HIGHWAY RESEARCH REPORT

DYNAMIC TESTS OF AN ENERGY ABSORBING BARRIER EMPLOYING WATER-FILLED PLASTIC CELLS

SERIES XXI

70-08

STATE OF CALIFORNIA BUSINESS AND TRANSPORTATION AGENCY DEPARTMENT OF PUBLIC WORKS DIVISION OF HIGHWAYS	MATERIALS AND RESEARCH DEPARTMENT RESEARCH REPORT NO. M & R 636405-3

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STATE OF CALIFORNIA—TRANSPORTATION AGENCY

RONALD REAGAN, Governor

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

5900 FOLSOM BLVD., SACRAMENTO 95819

November 1970
M&R No. 636405-3
Final Report

Mr. J. A. Legarra
State Highway Engineer

Dear Sir:

Submitted herewith is a research report entitled:

DYNAMIC TESTS OF AN

ENERGY ABSORBING BARRIER EMPLOYING

WATER-FILLED CELLS

SERIES XXI

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Very truly yours,

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ACKNOWLEDGEMENTS

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The following staff members of the Materials and Research Department contributed significantly to the success of the testing program reported herein:

Responsibility	Personnel
Project administration, barrier construction, preparation and operation of test vehicle and other test equipment, assembly of test movies and report.	Wallace Ames, Joseph Eagan, Joseph Halterman, Robert Field, Roger Pelkey, Lee Staus, Al Rybicki and Orvis Box.
Instrumentation of test barriers, test vehicles and dummies.	William Chow, Richard Johnson, Merle Wilson, Delmar Gans.
Data and documentary photography.	Robert Mortensen, Lewis Green.

REFERENCE: Nordlin, E. F., Woodstrom, J. H., and Doty, R. N., "Dynamic Tests of an Energy Absorbing Barrier Employing Water-Filled Cells"; State of California, Department of Public Works, Division of Highways, Materials and Research Department Research Report 636405-3.

ABSTRACT: The results of eight full scale vehicle impact tests into energy absorbing barriers employing water-filled plastic cells and cartridges are reported. This barrier absorbs the energy of an impacting vehicle through the movement of water horizontally, as the barrier is shortened, and vertically, through orifices, as the flexible water cells and cartridges are compressed.

The first four tests were of barriers approximately 16 feet long incorporating clusters of water-filled plastic cells placed between diaphragms fabricated with 6" x 6" timber. The barrier was restrained laterally and vertically with a single 3/4" diameter wire rope. Sedans weighing about 4700 pounds impacted the barrier head-on at speeds of from 15 to 60 mph. The results of these tests were very disappointing. However, a modified water-filled plastic cell barrier was designed and tested by the developer with greatly improved results. Consequently, four more tests of the modified design were conducted by the California Division of Highways.

These four additional tests were of a 19'-6" long barrier incorporating rows of flexible water-filled plastic cartridges placed between plywood panels oriented perpendicular to the barrier axis. Fiberglass coated plywood diaphragms were used for every fourth panel. Overlapping fiberglassed plywood "fender panels" were attached to each end of each diaphragm such that they would telescope during head-on impacts but redirect a vehicle if oblique angle impacts occurred. Lateral restraint was provided by two 7/8" diameter main cables plus two 3/8" diameter secondary cables.

Sedans weighing approximately 4700 lbs. impacted the barrier on the nose and side at speeds near 60 mph for this second series of four tests. The recorded vehicle passenger compartment decelerations indicated that although unrestrained occupants would sustain moderate to severe injuries, in most cases, during 60 mph collisions with this barrier design, fully restrained (lap belt and shoulder harness) occupants would sustain little or no injuries during the majority of 60 mph impacts into the nose or side of the barrier. In addition, the barrier did not generate unstable vehicle behavior and, in conjunction with the bridge approach guardrail backstop, effectively redirected a vehicle impacting from the side. The overall barrier performance showed significant improvement over the concrete wedge shaped deflectors currently in use in California on structure off-ramp gores.

KEY WORDS: Barriers, dynamic tests, impact tests, attenuation, bumpers, cushioning, energy absorbers, kinematics, vehicle dynamics

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I. INTRODUCTION

Ran-off-the-road type accidents accounted for approximately 50% of the fatalities on the California freeway system during 1967 and 1968. More than 50% of these ran-off-the-road fatalities involved collisions with fixed objects such as bridge abutments, bridge rail end posts, and large sign supports. Consequently, the California Division of Highways is now striving to provide a 30' wide recovery area alongside the traveled way free of unprotected fixed objects.

The provision of this protection for those fixed objects that cannot be removed or made "breakaway" has often been very difficult. One of the problems for which no satisfactory solution has been developed is providing protection from hazardous fixed objects located in the gore area at freeway off-ramps. Thus, the California Division of Highways has been involved in a research program for the last two years to investigate and/or develop energy absorbing barriers for use in gore areas.

An energy absorbing barrier is a cushioning device that can be placed in front of or around a fixed object. The barrier will absorb a large portion of the energy involved in a high speed headon or oblique angle impact, thereby reducing the deceleration force on the vehicle, and will usually decrease the severity of the injuries sustained by the vehicular occupants. Some of the variables that must be considered when designing these barriers include vehicle size, shape, speed, crushability, passenger compartment layout and construction; impact angle; occupant age, size, sex, physical condition, and use and type of restraint systems; and the physical limitations of space and, in some cases, anchorages on the freeway itself.

During 1967, forty full scale vehicle impact tests of barriers incorporating water-filled cells were conducted and reported by Brigham Young University researchers.[1] Based on the results of these tests and a few earlier unpublished tests by the original developer of this concept, John Rich Enterprises of Sacramento, California, the California Division of Highways, in 1968, undertook a series of eight full scale impact tests of barriers incorporating the water-filled cell concept. The results of these tests are reported herein.

The California Division of Highways has also tested two other types of energy absorbing barriers. The barriers utilized (1) 55-gallon steel drums, and (2) plastic drums containing sand. The results of the three tests of barriers employing steel drums can be found in Reference 2. The tests of the barrier employing sand will be reported during the spring of 1971.

II. OBJECTIVES

The objectives of this research were as follows:

I. Test the ability of a barrier incorporating water-filled plastic cells to control the behavior of a 4700 lb. vehicle impacting at speeds up to 60 mph such that:

A. The maximum average 40 millisecond (ms) deceleration sustained by the vehicle passenger compartment is no more than 12 G's;

B. The vehicle will not ramp, roll or spin out in a manner that will result in additional damage to it, injury to its occupants, or hazards to oncoming traffic because of its final position;

C. The vehicle will be redirected, during angular impacts into the side of the barrier, as effectively as it would be with a California standard anchored "W" beam guardrail.

II. Test the strength and durability of the barrier to verify that:

A. Collision with the barrier will not generate debris that would create a hazard for nearby uninvolved motorists;

B. The barrier will require a minimum of on-site repair work after a collision occurs.

III. Generate barrier modifications dictated by the barrier behavior during the tests.

IV. Make preliminary judgments about the cost and aesthetic properties of this barrier.

III. CONCLUSIONS

The following conclusions were based on an analysis of the results of the full-scale impact tests conducted during this test series:

1. The barrier design used in the first four tests, Nos. 211-214, is not recommended because of the severe damage sustained by the impacting vehicles and the unacceptable vehicular rise observed during the 60 mph, headon impact (Test 214).

2. The modified barrier design used for the last three tests, Nos. 216-218, is recommended for operational installations on a trial basis.

3. For the modified barrier used in Tests 216-218, the test objectives were achieved to the extent indicated below:

   a. The vehicular passenger compartment decelerations measured indicate that the occupants of vehicles impacting the barrier tested will have a good chance of sustaining little or no injury during high speed collisions if they are fully restrained (lap belt and shoulder harness). However, even unrestrained occupants will have a much better chance of surviving an impact with the barrier then they would have if colliding with a fixed object. This is particularly true at impact speeds less than 60 mph because the decelerations measured during the tests reported herein were well below those that would be experienced during collisions with a fixed object.[3]

   b. The post-collision trajectory of impacting vehicles will be acceptable in most cases. The final position of the vehicle may, however, be hazardous for adjacent traffic after oblique impacts against the side of the barrier.

   c. During Test 217, the vehicle was effectively redirected when it struck near the rear of the barrier; however, redirection appeared to be due more to the action of the bridge railing than to the fendering ability of the energy absorbing barrier. Despite the above observation, the fendering system is recommended on the basis of several tests by the developer in which test vehicles weighing around 4500 lbs. and traveling 50-60 mph impacted the side and the nose of the barrier at angles of 10-20° with the barrier axis and were effectively redirected.

d. The amount of debris generated during collisions with the water-cell barrier will not be excessive in most cases. However, during Test 217, several plywood fender panels were broken off. These fender panels, as well as the vehicle, may have been hazardous to adjacent traffic. Most of the water ejected during the tests traveled forward along the barrier axis. The effect of this spray on uninvolved motorists would be mainly psychological, and, hopefully, not too alarming, since the spray subsided very quickly. It should also be noted that none of the barrier components penetrated the vehicle passenger compartment.

e. The effort and number of barrier components required to place the barrier back in service will be minimal after headon and nearly headon impacts. A significantly greater effort will be required to repair the barrier after oblique angle collisions with its side (Test 217).

f. The cost of this barrier (design speed 60 mph) will be about $5,500 excluding site preparation, a backup structure, and installation charges. This initial cost is higher than several other types of energy absorbing barriers. However, the minimal cost of placing this barrier back in service, as compared with barriers requiring complete replacement after impacts occur, will offset this high initial cost to some extent.

g. The slightly tapered, simple shape of this barrier should not be aesthetically obstrusive in a gore area. The side fender panels lend themselves to painting for safety and/or decorative purposes.

h. Minor drawbacks to this barrier system include the problems that might arise in protecting water in the cells from leakage, vandals and freezing. Also, the barrier is more complex than most other highway barriers and, as such, would require skilled construction and maintenance personnel as well as a relatively large number of maintenance components as compared to most other highway barriers.

i. Since most of the test objectives were successfully met using a moderately heavy passenger vehicle impacting at relatively high speeds, this barrier should perform with reasonable effectiveness under the range of conditions which constitute the majority of gore area impacts. Consequently, the use of energy absorbing barriers incorporating water-filled cartridges has been recommended and two trial installations are scheduled for installation on California freeways prior to June, 1971.

IV. DESCRIPTION OF TEST PROCEDURE

All eight tests were conducted on a section of runway at an airport near Lincoln, California. The vehicles used for this series of tests were 1966 and 1968 Dodge sedans. The vehicles weighed about 4700 lbs. including dummies and instrumentation. Control of the vehicles was accomplished by a remote operator following 200 feet behind the test vehicle in a car equipped with a tone transmission system. References 4 and 5 contain a description and some photographs of this control equipment.

A "trip line" placed in the vehicle path cut off the ignition just prior to impact. The test vehicle's remotely controlled brakes were not applied before or during impact. Five tape switches were placed at ten foot intervals forward of the point of impact and were actuated by the approaching test vehicle. The last tape switch was placed so that the vehicle passed over it when impact with the barrier took place. Tire contact with these tape switches triggered a series of five flash bulbs located in view of all data cameras.

All the tests were recorded with high speed (250-400 frame per second) motor driven Photosonic cameras which were manually actuated from a central control console. These cameras were located on both sides of the barrier and on a 30 ft. light standard directly above the point of impact. Targets on the side of the vehicle and a target board (Tests 215 through 218 only) on the roof of the vehicle were used for reduction of the data film taken during each test.

Another Photosonic camera was located in the vehicle passenger compartment to film the movement of the dummies. This camera was started by means of a pin-actuated switch mounted on the rear bumper of the test vehicle. The release pin was attached to a 50 foot length of nylon line anchored in the pavement behind the vehicle at its starting position.

A motor driven Hulcher camera with a speed of approximately 20 frames per second was located on scaffolding and provided documentary coverage of the tests. Ground-mounted high speed and normal speed cameras were hand panned through impact. Still photos, slides and documentary movies of the test barrier and vehicle were also taken.

Some of the Photosonic cameras were provided with a 1000 cycle per second timing light generator that impressed a red-orange pip on the edge of the film. These pips were used to determine the frame rates of the cameras.

V. TEST RESULTS

Summary

Two basic types of barriers incorporating water-filled components were tested. These two barrier types and their modifications are described below for each of the eight tests which were conducted. The primary variables, in addition to the barrier type, were the impact speeds of the vehicles and the angles and locations of impact into the barrier. The following table summarizes these impact conditions:

Test Parameters

Barrier Type	Test No.	Impact Speed (MPH)	Location on Barrier of Impact	Angle with Barrier Axis of Impact
"First Generation"	211	14.7	Nose	0° - Headon
	212	33.3	Nose	0° - Headon
	213	48.2	Nose	0° - Headon
	214	59.8	Nose	0° - Headon
"Second Generation"	215	57.5	Nose	0° - Headon
	216	61.8	Nose	0° - Headon
	217	57.0	Side*	9°
	218	59.0	Nose	8°

*13'-0" behind the nose

Descriptions of each test are included below. Each test description contains the test parameters, a description of the barrier tested, the damage sustained by the impacting vehicle and its behavior during impact, the damage sustained by the barrier, the reactions of the dummies, and a description of the instrumentation used and the results obtained. Also included are data sheets for each test that summarize the significant measurements and parameters. Additional data for each test are included in the Appendix. No accelerometer data are included in the Appendix for Tests 211-214 due to the unsatisfactory performance of the barriers and the somewhat marginal performance of the instrumentation system. The accelerometer data included in the Appendix for Tests 215-218, as transferred to graph paper, includes all the significant values shown on the original or filtered trace.

The decelerations included in the descriptions of each test are averages of the highest average decelerations sustained by the vehicle passenger compartment or the dummy over a 50 millisecond (ms) period unless otherwise noted. These measurements were taken using Statham strain gage type accelerometers mounted on the vehicle floor and on the back of the dummy's chest. A discussion of the processing and interpretation of this type of data is included in Reference 2.

The interpretation of the measured vehicular decelerations was accomplished using the tolerance limits shown below. Injury severity predictions are related only to the direction of deceleration that appears to be most critical (i.e., no vectorial addition of deceleration was accomplished). References 2 and 4 contain a discussion of deceleration tolerances and the reasoning behind the choice of these values. These limits define what would be, in the opinion of the researchers, a survivable environment under almost all circumstances.

DECELERATION LIMITS (G's)

Occupant Restraint	Vehicle Passenger Compartment - Highest 50 ms avg. Lateral	Longitudinal	Total
Unrestrained	3	5	6
Lap belt	5	10	12
Lap belt and shoulder harness	15	25	25

B. Test 211

Barrier Description: The cells used in the barrier were plastic cylinders with a 6" outside diameter, 1/4" wall thickness, and 41" length. The tops of the cells contained several 3/4" diameter orifices. The test barrier contained ten cell-clusters of 12 cells each (see Exhibit 1). Cell-clusters were arranged in groups of two, one on each side of the barrier, and separated with timber diaphragms. A larger cell cluster, approximately 12 cells wide by 4 cells deep, formed the nose of the barrier. A total of 167 cells were used for the barrier. The barrier was 15 feet long and varied in width from 5'-6" at the nose to 8'-0" at the rear (see Figure 1, below).

One 3/4" diameter wire rope was placed on the barrier axis approximately 6 inches above the runway surface and fastened to a deadman anchor in front of the barrier and the base of the camera tower located within the "U" shaped concrete backstop behind the barrier. This cable was intended to provide lateral and vertical barrier restraint. Smaller wire rope was placed on both sides of the barrier and was used to reposition the barrier after it had been compressed during impact. Thirteen of the cells in the nose cluster contained no water.

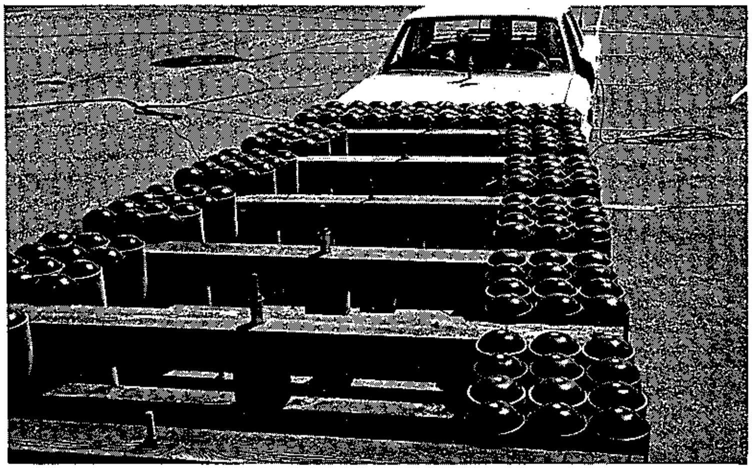
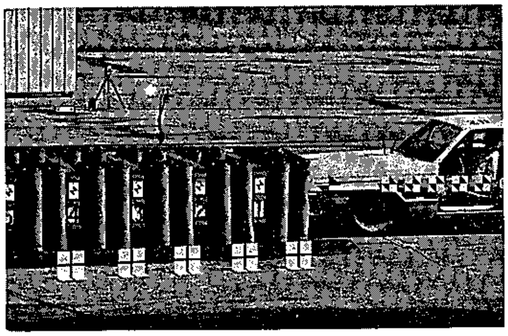


Figure 1

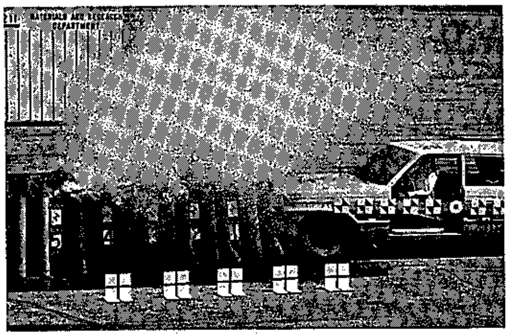
Results: See Plate 1 (page 11) for a summary of the test results. A 4680 lb. Dodge impacted the test barrier headon at a speed of 14.7 mph. The crash vehicle came to a relatively smooth stop while sustaining no damage. Vehicle rise was three inches. There was no measurable deformation of the steering wheel. Maximum penetration of the crash vehicle into the barrier was five feet. The post impact position of the leading edge of the barrier was 4'-1" behind its pre-impact position. The barrier was undamaged. The weight of water expelled from the cells was 922 lbs.

Instrumentation - Description and Results: See Exhibit 2 for the barrier instrumentation layout. Pressure transducers were placed in four cells near the front of the barrier to measure the water pressure during impact. The maximum water pressure recorded was 25 psi. A transducer placed on the lateral restraint cable indicated that a maximum load of 1150 lbs. was sustained during impact. Vehicular deceleration was measured in the passenger compartment with an Impact-O-Graph. Even though this instrument is not accurate for vibrations over 23 Hertz (Hz), the values obtained do provide a relative comparison between tests. Thus, G values from the Impact-O-Graph should not be considered as any more than an approximation of the decelerations sustained during the collision. The peak vehicle deceleration indicated by the Impact-O-Graph was 4 G's.

PLATE 1



Impact



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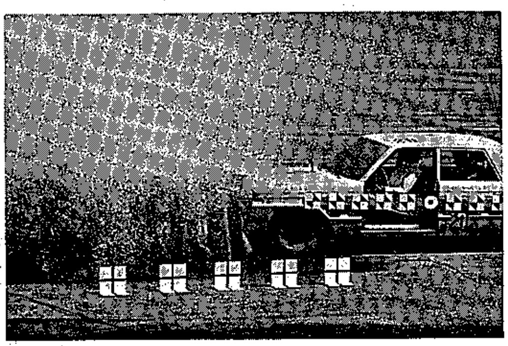

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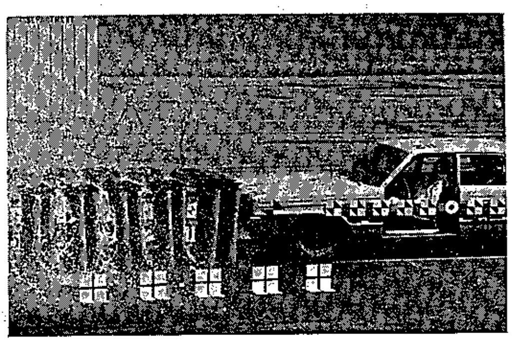

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Barrier Depth	15.0 Ft.
No. of Water-Filled Cells	167
Permanent Displacement of Barrier Nose	4.1 Ft.
Deceleration Distance-Passenger Compartment	5.0 Ft.
Maximum Vehicular Deformation	None
Passenger Compartment Deceleration (Peak-Impactograph)	4 G's
Vehicle Average Deceleration-Calculated	1.5 G's

Test No.	211
Date	6-27-68
Vehicle	1966 Dodge
Vehicle Weight (W/Dummy and Instrumentation)	4680 Lbs.[1]
Impact Velocity	14.7 mph
Impact Angle	Head-on
Dummy Restraint	None

[1] Left front door removed.

C. Test 212

Barrier Description: The test barrier was the same one used for Test 211 (see Exhibit 1).

Results: See Plate 2 (page 14) for a summary of the test results. A 4680 lb. Dodge impacted the test barrier headon at a speed of 33.3 mph. The test vehicle did not stop quite as smoothly as it did for Test 211. Vehicle rise was 4-1/2 inches. Damage to the vehicle was moderate and included deformation of the grill, front bumper, and front of the hood (see Figure 2, below). The exhaust manifold was broken near its attachment to the engine block and the radiator was forced back into the V-belt lower pulley. The post behind the front door (removed for the test) on the drivers side failed at its connection with the roof (see Figure 3, below). The permanent deformation of the steering wheel was 2" (see Figure 4, below).

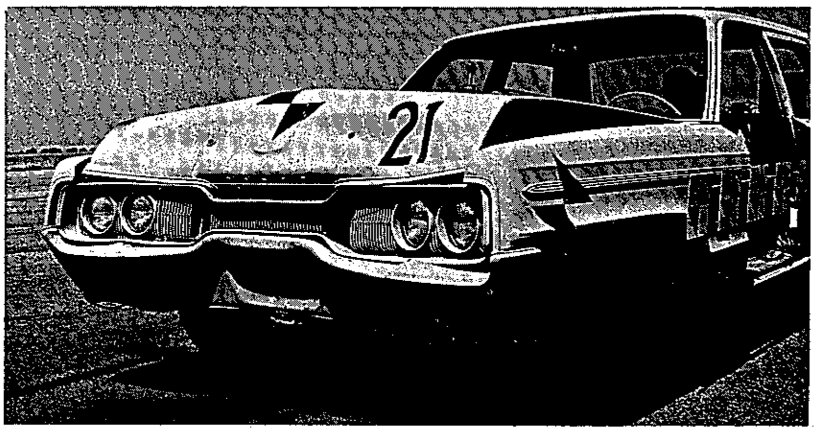


Figure 2

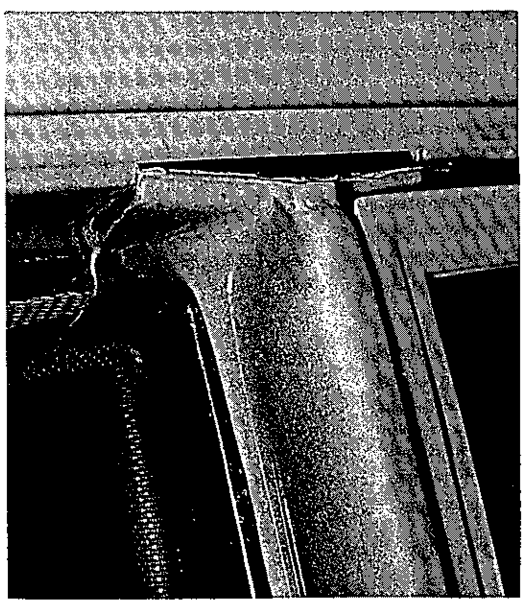


Figure 3

Figure 4

Only minor damage was sustained by the barrier (see Figure 5, below). Four evaporation caps were blown off water cells in the nose cluster and some crosby clips on the guide cable were jammed against the cable guide in diaphragm No. 5. The concrete backstop was shifted back one inch. Maximum vehicular displacement of the barrier was 8'-4"; the post impact location of the leading edge of the barrier was 6'-6" behind its pre-impact position. A total of 2250 lbs. of water was expelled from the cells.

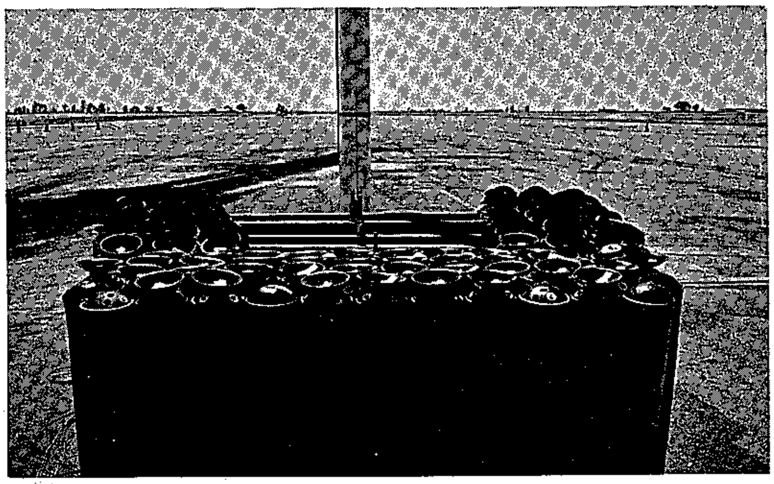
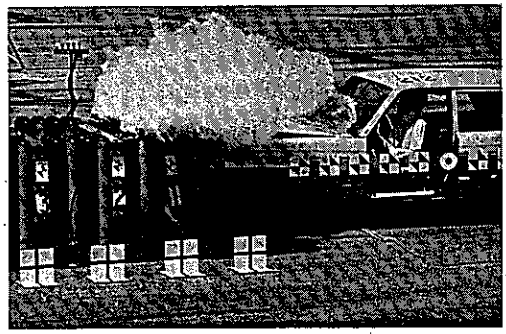


Figure 5

<u>Instrumentation Description and Results:</u> Instrumentation was identical to that used for Test 211 (see Exhibit 2). The maximum reading from the pressure transducer in the water-filled cells was 48 psi and the maximum load on the lateral restraint cable was 2350 lbs. Peak vehicle "deceleration" measured on the Impact-O-Graph was 20 G's.

PLATE 2



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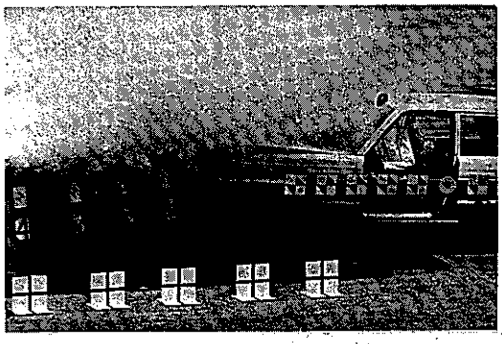

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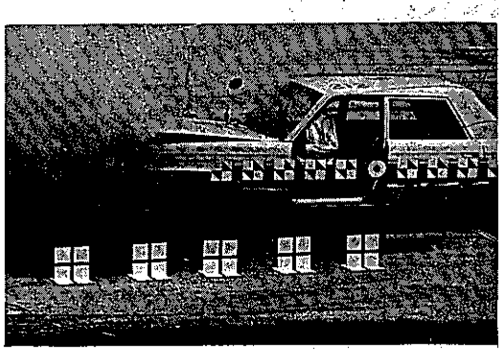

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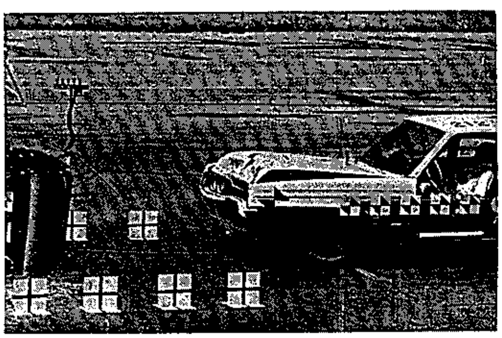

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Barrier Depth	15.0 Ft.	Test No.	212
No. of Water-Filled Cells	167	Date	6-27-68
Permanent Displacement of Barrier Nose	6.5 Ft.	Vehicle	1966 Dodge[1]
Deceleration Distance-Passenger Compartment	9.1 Ft.	Vehicle Weight	4680 Lbs.[1]
Maximum Vehicular Deformation	8 In.	(W/Dummy and Instrumentation)	
Passenger Compartment Deceleration	20 G's	Impact Velocity	33.3 mph
(Peak-Impactograph)		Impact Angle	Head-on
Vehicle Average Deceleration-Calculated	4.1 G's	Dummy Restraint	None

[1] Left front door removed.

D. Test 213

Barrier Description: The test barrier used was identical to that used for Test 211 and 212 with the following exceptions: (1) a triangular shaped cell-cluster was used on the nose of the barrier; (2) the back row in this cluster had alternate full and empty cells; (3) some cells had water in their upper portion only; (4) overall barrier length was increased to 16'-3"; (5) evaporation caps were removed from all the cells in the barrier; and (6) the number of orifices in some of the rear cells was increased (see Figure 6, below). The total number of cells in the barrier was 165. See Exhibit 3 for additional details of the test barrier.

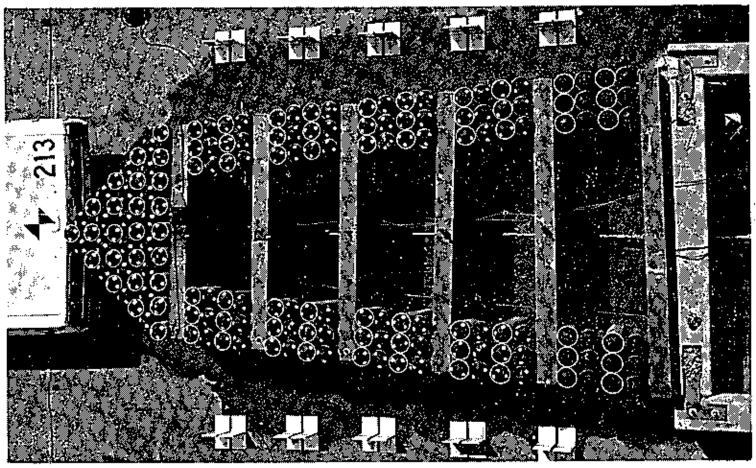


Figure 6

Results: See Plate 3 (page 18) for a summary of the test results. A 4600 lb. Dodge impacted the test barrier headon at a speed of 48.2 mph. During impact, the vehicle rode up on the barrier nose. Vehicle rise was 11 inches. The vehicle fan and radiator were jammed up against the engine block. There was severe damage sustained by the grill, front bumper, and front of the hood of the test vehicle (see Figure 7, below). The body of the vehicle was deformed over the door post and in front of the front door hinges on both sides, indicating a severe buckling failure of the vehicle chassis (see Figure 8, below). There was severe buckling of the right front fender and minor buckling of the left front fender. There was moderate buckling of the floor board in the rear of the passenger compartment. The impact force of the dummy, restrained by both a lap belt and single diagonal shoulder harness, caused a 2-1/2 inch permanent deformation in the steering wheel. The driver's seat came loose on its guides although the guides remained firmly attached to the floorboard. There was some fraying of the shoulder harness near its connection to the lap belt. The vehicle was considered a total loss.

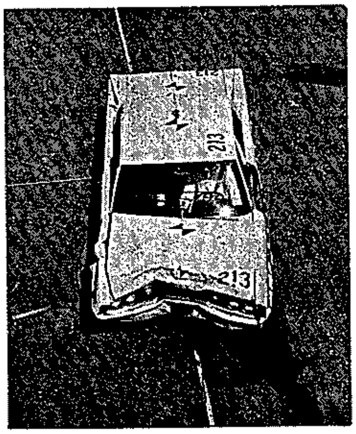


Figure 7

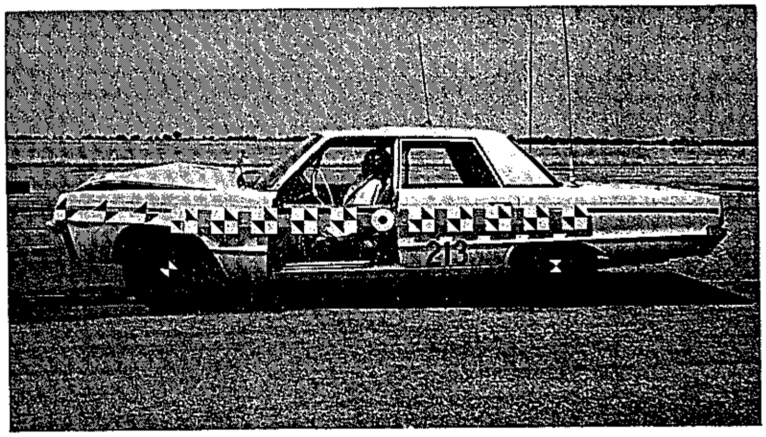


Figure 8

Barrier damage consisted of 26 orifice plugs ejected, a deformed "through" bolt at the left end of Diaphragm No. 6, splitting of the left end of the middle 6" x 6" timber on Diaphragm No. 6, and one broken pressure transducer (see Figure 9, below). Maximum vehicular displacement of the barrier was 12'-5". The post impact position of the leading edge of the barrier was 6'-2" behind its pre-impact location.

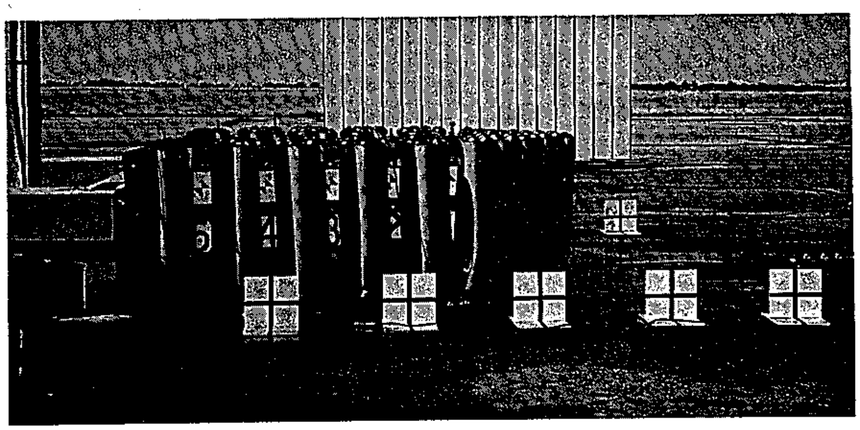


Figure 9

<u>Instrumentation Description and Results</u>: An instrumentation system on loan from the Federal Highway Administration was used for this and the succeeding tests.[6] This system (the Wyle System) consisted of seven channels of FM telemetry for use on the crash vehicle and dummies and seven channels of hardwire equipment for use on the barrier. The system included seven accelerometers and two seat belt force transducers and all the necessary signal conditioning equipment for their use. The dynamic data from these transducers was recorded on a 14 channel analog magnetic tape recorder. (A description of the instrumentation from which useful data was obtained is included as Exhibits 4 and 5.) Tape switches were located in the vehicle path to provide an "event marker" signal. This event marker was recorded, along with the accelerometer data, on the tape recorder. Concurrently, a 100 millisecond time cycle was also recorded on the tape recorder.

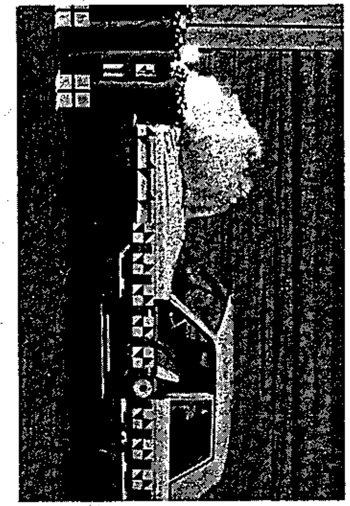
After the test, the data on the tape was played back through a visicorder which produced an oscillographic trace (line) on paper. Each paper record contained one accelerometer data trace, the event marker trace, and the 100 millisecond time cycle trace.

The accelerometer data was filtered at 96 Hertz (Filtering is an integration process which removes the high frequency spikes of acceleration and produces a smoothed out curve) This filtered trace was also reproduced on a paper record with the time cycle and event marker traces. In addition to eliminating a large portion of the high frequency noise, this filtration permitted easier comparison of different accelerometer records.

Only six channels appeared to have usable data. However, calibration problems were experienced so even the data on these six channels is subject to question.

An accelerometer in the chest of the dummy measured a peak deceleration of 28.0 G's; an accelerometer mounted on the floor of the test vehicle over the transmission showed a peak deceleration of 24.6 G's. The force on the lap belt was 2210 lbs. A peak cable load of 6280 lbs. was recorded. Pressure transducers (not a part of the Wyle System) were again placed in several water-filled cells and measured pressures of up to 145 psi. The Impact-O-Graph reading for the peak vehicular deceleration was 15 G's.

PLATE 3



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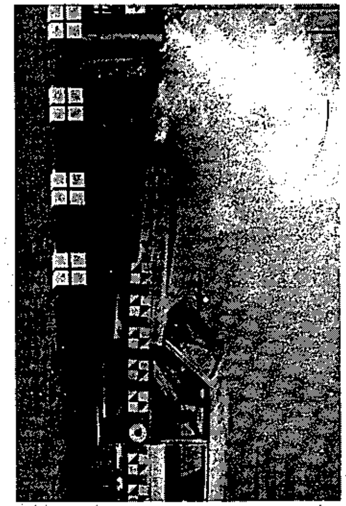

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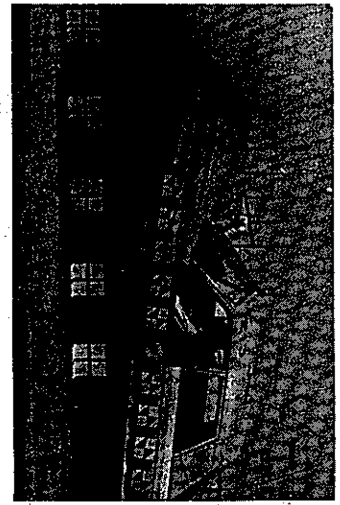

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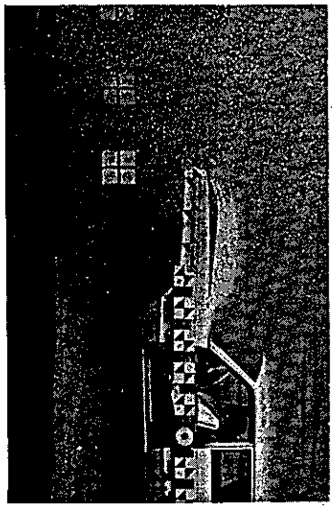


I + 1.99 Sec.

Barrier Depth	16.4 Ft.
No. of Water-Filled Cells	165
Permanent Displacement of Barrier Nose	6.2 Ft.
Deceleration Distance-Passenger Compartment	13.5 Ft.
Maximum Vehicular Deformation	13 In.
Passenger Compartment Deceleration (Peak-Impactograph)	15 G's
Vehicle Average Deceleration-Calculated	5.7 G's

Test No.	213
Date	8-8-68
Vehicle	1966 Dodge
Vehicle Weight (W/Dummy and Instrumentation)	4600 Lbs.[1]
Impact Velocity	48.2 mph
Impact Angle	Head-on
Dummy Restraint	Lap belt and single shoulder harness

[1] Gas tank and left front door removed.

E. Test 214

Barrier Description: Additional barrier modifications were made due to the severity of the impact in Test 213. The first three diaphragms were replaced with fiberglass coated plywood hollow core structures. Honeycomb paper was placed in the core to obtain a more rigid structure. A significant weight reduction (28%) in the first three diaphragms was thus realized while maintaining approximately the same rigidity. Another significant change was the use of a "sandwich" arrangement of cells and 5/8" plywood panels between Diaphragm Nos. 1 and 2 (see Figure 10, below). This arrangement was used to further decrease the mass of the barrier nose and to obtain better efficiency from the water cells placed between the leading diaphragms. The water in the nose cells was centered at the cell mid-height. The water in all the other cells was in the top portion. There was a total of 150 cells in the barrier, many of which did not contain water. See Exhibit 3 for additional barrier details.

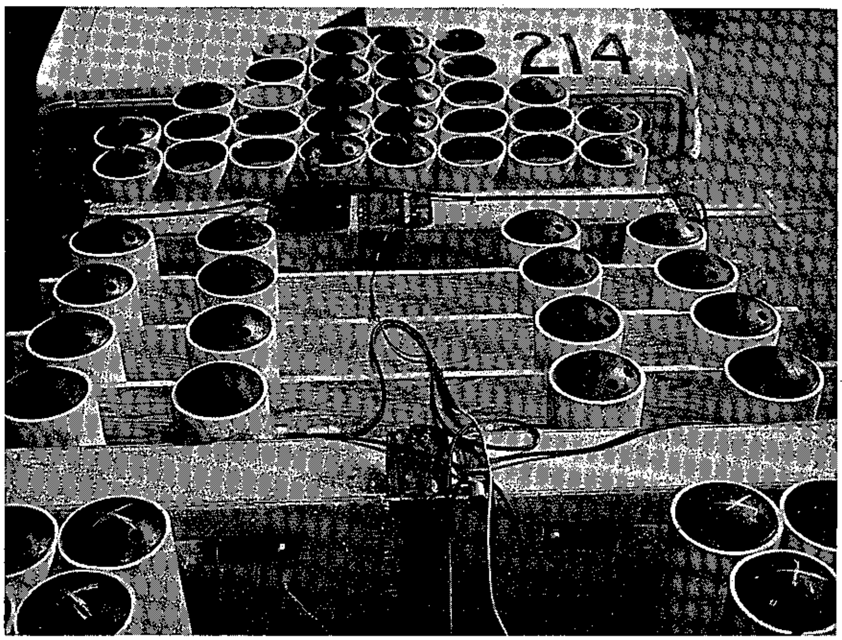


Figure 10

Results: See Plate 4 (page 22) for a summary of the test results. A 4600 lb. Dodge impacted the barrier headon at a speed of 59.8 mph. The vehicle penetrated approximately 10.5 ft., rolled to the right, pivoted about its right rear wheel and then right corner of the rear bumper, and forced the nose of the barrier up approximately 10 ft. into the air. Rise of the front of the vehicle was about 9'. The vehicle came to rest 9 inches from the barrier nose at an angle of 41 degrees with the approach line and off-set approximately 5.5 ft. from it. The vehicular rise was enough to cause contact of the bottom of the rear bumper with the runway surface.

The following vehicular damage was sustained. The fan and radiator were jammed up against the front of the engine block, which appeared to be displaced slightly to the rear. There was severe damage to the grill, front bumper, and front of the hood of the test vehicle. The body of the vehicle buckled over the door posts and in front of the front door hinges on both sides, indicating severe buckling of the vehicle chassis. There was severe buckling of the left front fender and minor buckling of the right front fender. Maximum deformation of the front of the vehicle was 2 ft. (see Figure 11, below). There was some displacement of the dashboard into the passenger compartment and 4-1/2 inches of steering column projection into the passenger compartment. The impact force of the dummy caused a 3-3/4 inch permanent deformation in the steering wheel (see Figure 12, below). Stitching of the diagonal shoulder harness frayed near the connection of the shoulder harness to the lap belt.

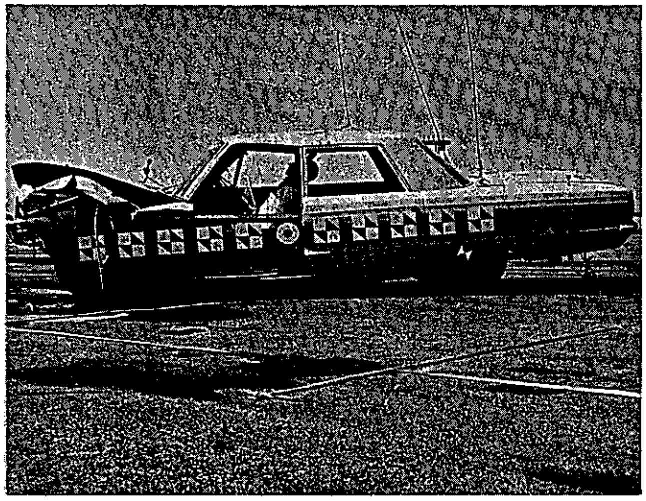


Figure 11

Figure 12

The barrier was twisted such that the center of the nose was displaced 3 ft. back and 2 ft. to the right of its original position (see Figure 13, below). Barrier damage consisted of separation between four pairs of cells, bending and crushing failures of Diaphragm Nos. 1, 2, and 3, splitting of spacer blocks in Diaphragms 4 and 5, failure of the legs of all three 5/8 inch plywood panels, and failure of all the components of the "rigid" backstop. The most significant failure was of the center cable attachment to its front anchor. Slipping of the "dead" end of the cable through the cable clips was the cause of failure. Although the number and spacing of the clips was less than the industry's recommendations (due to the proximity of the barrier nose with the anchor), this same system sustained over 6000 lbs. of tensile load during Test 213. This cable failure did significantly alter the barrier performance after cable slip occurred. Also, the turnbuckle strain gage data indicates that the 4000 lb. cable preload was, for some unexplained reason, lost prior to impact. This also altered the barrier's resistance to upward movement.

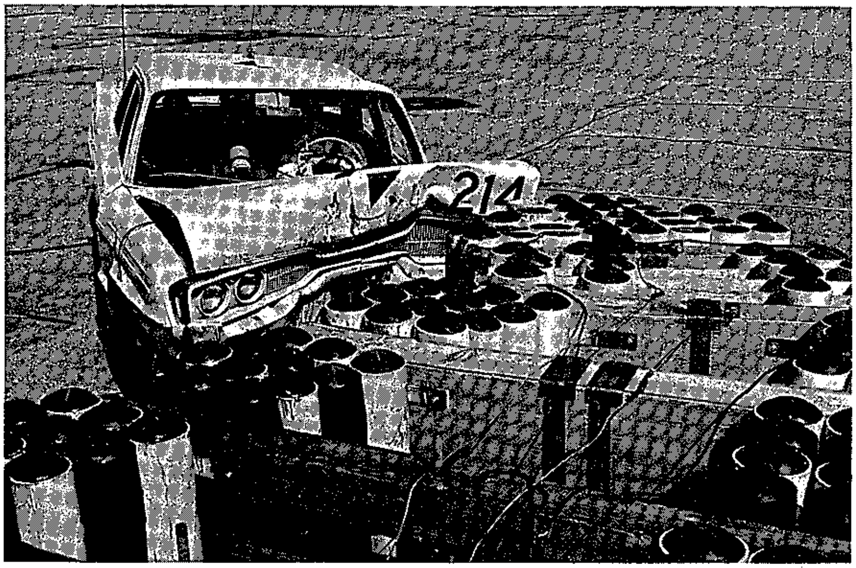
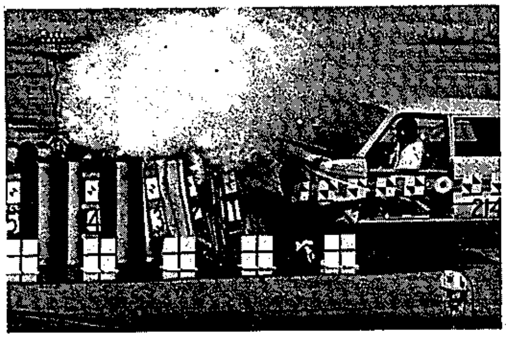


Figure 13

<u>Instrumentation - Description and Results</u>: The instrumentation used for Test 214 was similar to that in Test 213 (see Exhibits 4 and 5).

The maximum pressure transducer reading from the water-filled cells was 185 psi; the maximum load on the guide cable turnbuckle was 4400 lbs. The maximum indicated load on the lap belt was 1400 lbs. and the peak load on the shoulder harness was 1065 lbs. Four accelerometers were mounted on the floor of the vehicle. One, at the center of gravity, had a peak reading of 15.8 G's, and there were peak readings of 17.2 G's 22 inches forward of the c.g., 13.3 G's at the left rear, and 16.9 G's at the right rear. The accelerometer readings from the barrier and dummy were erroneous. The Impact-O-Graph showed a peak vehicular deceleration of 15 G's.

PLATE 4



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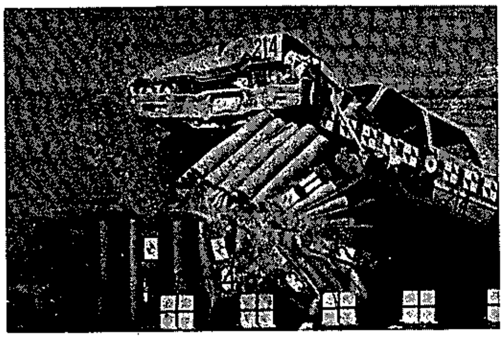
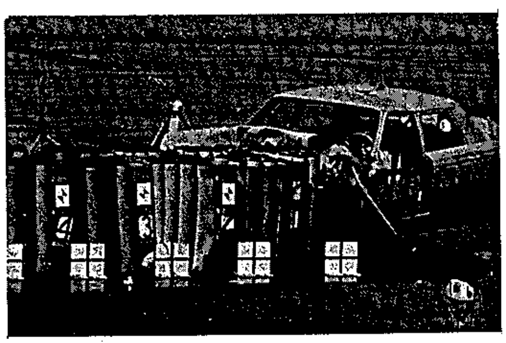


I + 0.93 Sec.

I + 1.45 Sec.



I + 3.66 Sec.

Test No.	214
Date	9-25-68
Vehicle	1966 Dodge[1]
Vehicle Weight (W/Dummy and Instrumentation)	4600 Lbs.
Impact Velocity	59.8 mph
Impact Angle	Head-on
Dummy Restraint	Lap belt and single shoulder harness

Barrier Depth	16.2 Ft.
No. of Water-Filled Cells	150
Permanent Displacement of Barrier Nose	3.2 Ft.
Deceleration Distance - Passenger Compartment	-
Maximum Vehicular Deformation	24 In.
Passenger Compartment Deceleration (Peak-Impactograph)	15 G's
Vehicle Average Deceleration-Calculated	

[1] Gas tank and left front door removed.

Summary:

The results of these four tests of the "first generation" barrier design were very disappointing. Consequently, it was tentatively decided to discontinue further testing of this concept in favor of some other, more promising concepts.

However, while final analysis of these four tests was still in progress, the manufacturer of the barrier established a test site near Sacramento and began a series of full-scale developmental tests of a significantly different barrier incorporating water-filled containers. Over ten of those tests were conducted with impact on the side of the barrier and the remainder with impact into the barrier nose, either at a 10° angle with the barrier axis or on the barrier axis. Representatives of the Division of Highways witnessed many of these tests.

It was obvious that definite and significant design improvements were being realized. Consequently, an additional series of four tests of redesigned "second generation" barriers incorporating water-filled containers was conducted by the Division of Highways. Many of the modifications to the barrier design that were developed by the barrier manufacturer during his test series were incorporated into the barriers that are described below.

Test 215

Barrier Description: A completely new barrier was built for Test 215 (see Exhibit 6). Overall dimensions of the barrier were a 19'-6" length, a 3'-0" width at the nose, and a 7'-0" width at the back of the barrier (see Figure 14, below). The basic module of the barrier consisted of four rows of cartridges separated by 1-1/2 inch fiberglass coated plywood diaphragms; there were eight modules in the barrier plus a cluster of cells (containing cartridges) at the nose. Between diaphragms, each row of cartridges was separated by an interior panel of 1/2 inch duraply plywood. There were three to five water-filled cartridges in each row (see Figure 15, below). Along the sides of the barrier, fender panels of 1-1/4 inch fiberglassed plywood were hinged to each diaphragm at the noseward side of the panel (see Figure 16, below). The length of these fender panels was such that they overlapped. Thus, backward movement (compression) of the barrier was not hindered. The fender panels were attached with springs to the next rearward diaphragm. Fiberglassing was used to provide not only additional strength but also a low friction surface between the fender panels and the impacting vehicle. These fender panels were developed for the purpose of redirecting vehicles that impacted the side of the barrier rather than permitting pocketing into the barrier.

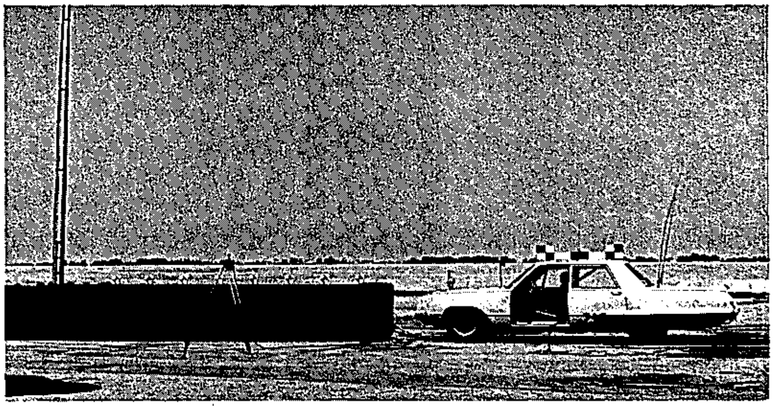


Figure 14

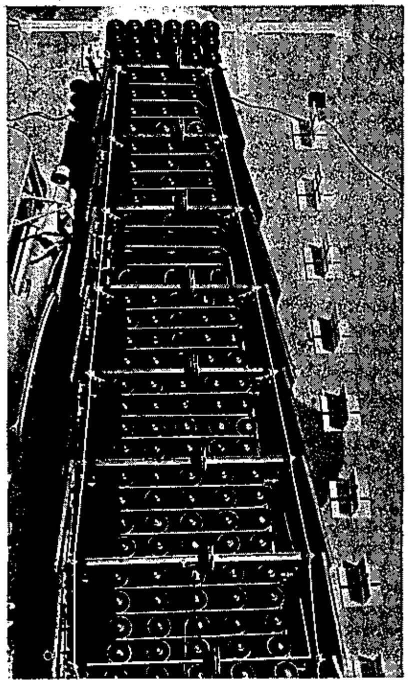


Figure 15

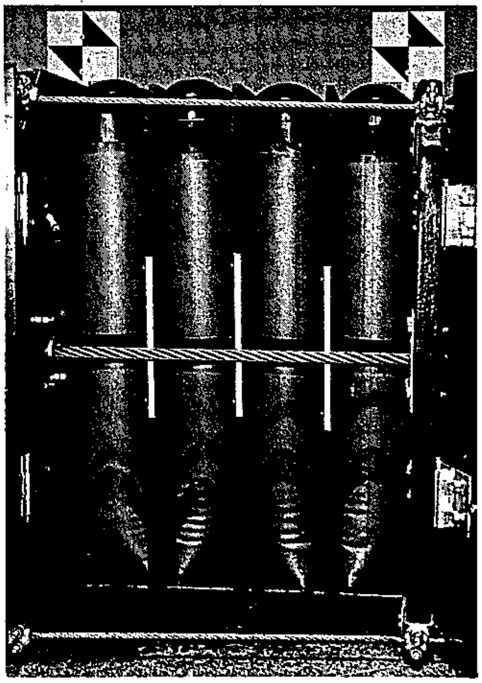


Figure 16

Interior panels and diaphragms both rested on steel straps attached to the runway surface to decrease the coefficient of friction between the barrier and the runway surface.

The cartridges used in the eight modules (120 total) were a thin vinyl-coated nylon fabric and were 24, 30 and 36 inches long. Their outside diameter was 5-1/2 inches. These "cartridges" had the same caps (with orifices) that were used on the "first generation" barrier for Tests 211-214. These cartridges were slipped through 1/4 inch thick vinyl supporting rings which were fastened to the interior panels or diaphragms. The water-filled cells used in the nose of the barrier (18 total) were six inches in diameter, 41 inches long, and contained 1/4 inch thick vinyl walls. These cells were the same type as those used for tests 211-214 and they rested on the ground. All the cartridges, with the exception of those containing the pressure transducers, had solid vinyl evaporation caps permanently attached with aluminum pop rivets (see Figure 17, below). All the cartridges were filled with water but only six of the 18 nose cells contained water.

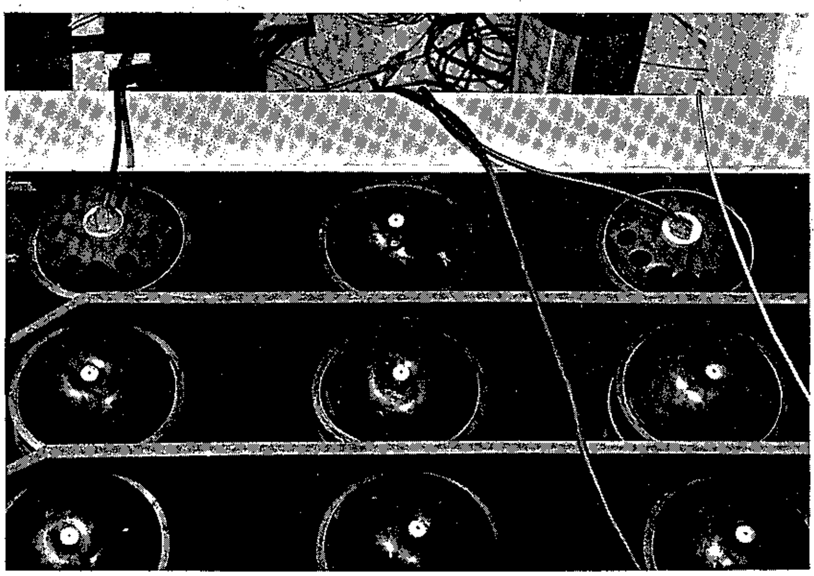


Figure 17

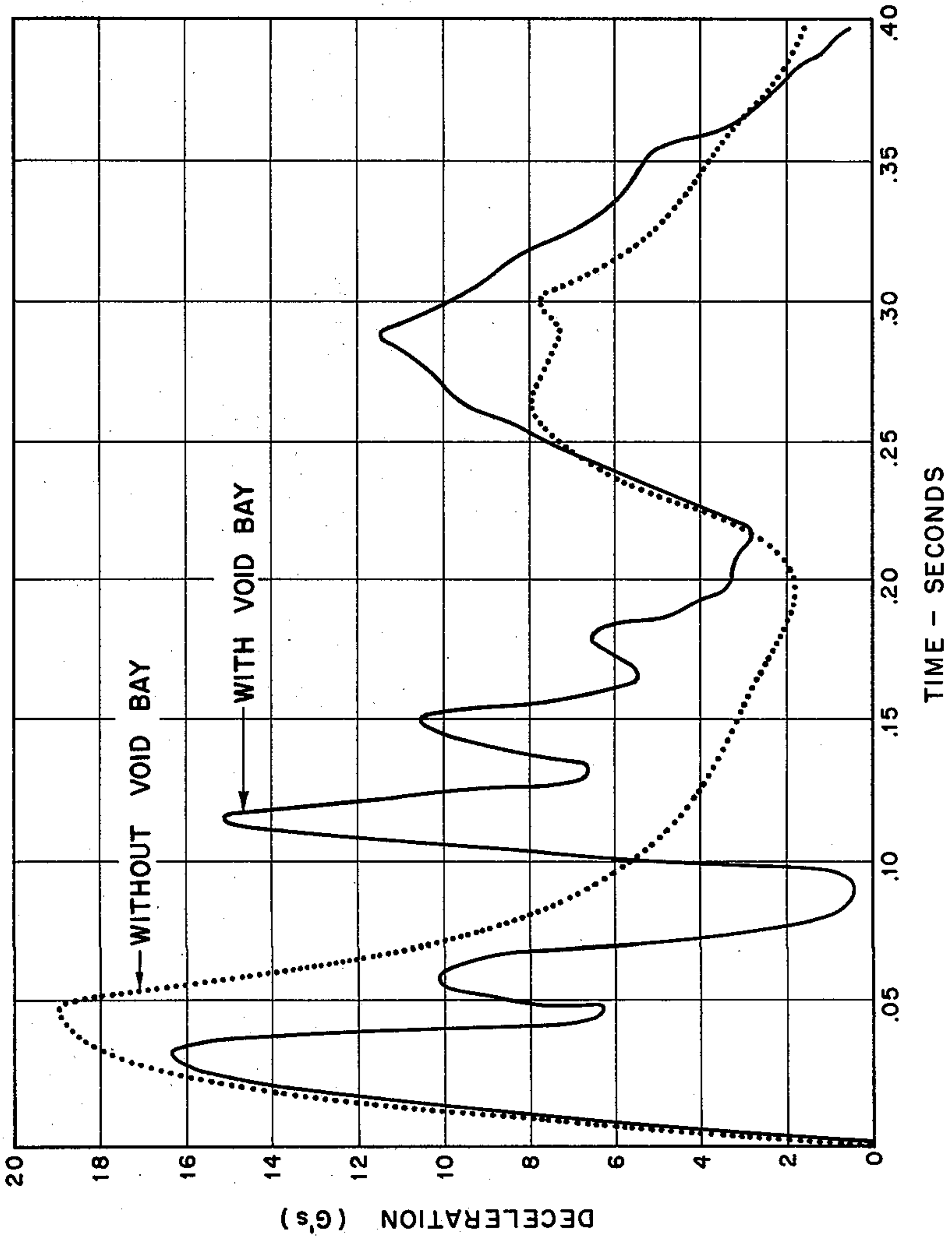
The third module back from the nose of the barrier contained no cells or cartridges. The developers advised the use of this empty or void space for better dynamic response of the barrier. The theoretical effect of the void bay can be seen on Plate 5, page 26.[7]

Wire ropes were used to stabilize the entire barrier. Two parallel 7/8 inch preformed galvanized 6 x 19 wire ropes with independent wire cores extended from steel plates attached to a concrete anchor block in front of the barrier nose back through fabricated steel guides in the diaphragms to the backup bridge rail at the rear of the barrier. These cables were designed to give the barrier lateral and vertical stability and limit pocketing during side angle impacts. Two secondary cables of 3/8 inch wire rope were used to stabilize the barrier nose during a side angle impact (see Figure 18, below). They were attached at the anchor block and first diaphragm; each cable had a shear pin with a 4000 lb. shear resistance value. After the barrier had

PLATE 5

THEORETICAL DECELERATION — VEHICLE
9-BAY HI-DRO CUSHION BARRIER

VEHICLE WEIGHT 4720 LBS
IMPACT VELOCITY 60 MPH



been compressed due to an impact, 3/8 inch wire ropes were used to stretch out the barrier and reposition it. These wire ropes were attached to the upper and lower corners of each end of each diaphragm (see Figure 19, below).

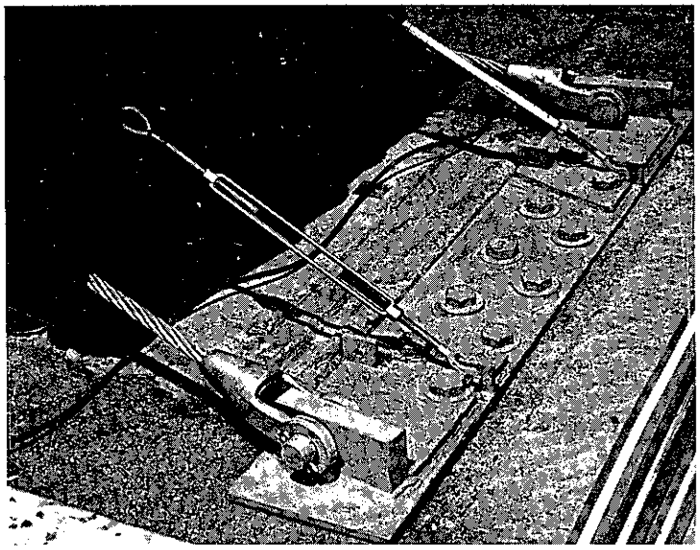


Figure 18

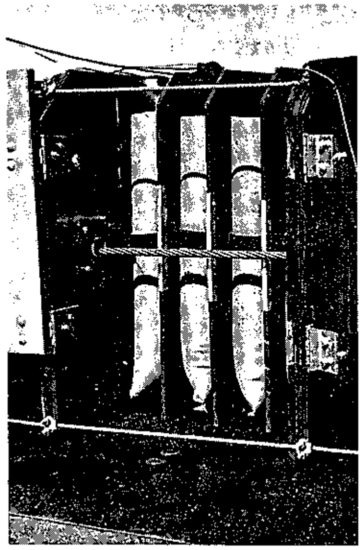


Figure 19

Additional weight was added to the diaphragms near the rear of the barrier. Diaphragms 6 and 7 contained two 1/4 inch steel plates in addition to the 1-1/2" fiberglass coated plywood. Diaphragm 8 consisted of two 1/4 inch steel panels and one 12 gauge steel sheet. This additional weight was also suggested by the developer to improve the barriers dynamic response.[7]

The test barrier required a rigid backup structure. For Tests 215 through 218, a bridge approach guardrail nose structure typical of a gore installation was used (see Exhibit 7). In addition, a fabricated steel plate backup panel was attached to the nose of the bridge rail to provide a large bearing area for the barrier during impact (see Figure 20, below).

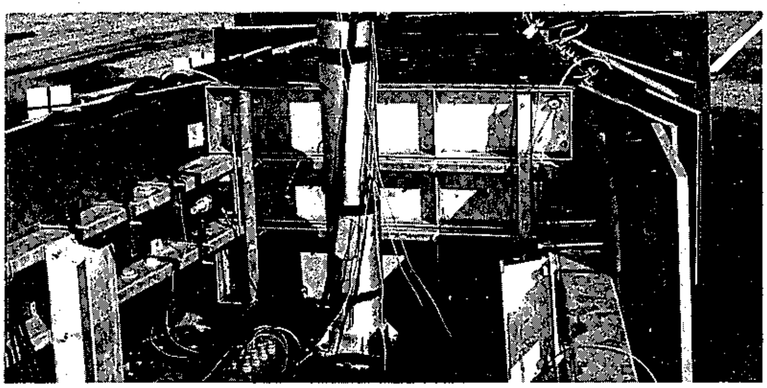


Figure 20

Results: See Plate 6, page 31, for a summary of the test results. A 1968 Dodge impacted the barrier headon at a speed of 57.5 mph. As rearward displacement of the barrier began, the fender panels rotated downward such that their lower rear corners penetrated into the asphalt concrete runway and restricted backward movement of the barrier. This, plus an 18 inch vehicle offset at impact, resulted in a lifting, rolling motion being imparted to the test vehicle. The vehicle traversed a 360° roll off to the right side of the barrier and came to rest several feet behind and to the right of the barrier (see Figure 21, below). Front end crush varied from 0 to 20 inches; maximum crush was on the left side (see Exhibit 8). The top caved in, the windshield was broken, the left rear wheel was bent, the left rear door jammed, and there were scrapes over much of the surface of the vehicle. However, off-center impacts on any barrier nose <u>may</u> inherently cause this type of vehicle instability due to the unsymetrical rise of the vehicle fore-structure. There was no measurable deflection of the collapsible steering column.

Figure 21

The barrier remained intact; however, some damage was sustained (see Figure 22, below). Many of the fender panels were scarred and most were damaged on the rear bottom corners where they were thrust into the ground as the barrier was compressed (see Figure 23, below). The edges of several diaphragms were broken or showed delamination of the plywood; hinges between fender panels and diaphragms were bent or broken in several locations. Damage was less severe towards the rear portion of the barrier. Interior panels were undamaged behind the void module (third section back of the nose). There was no damage to the steel backup structure. Barrier displacement was 9.3 feet.

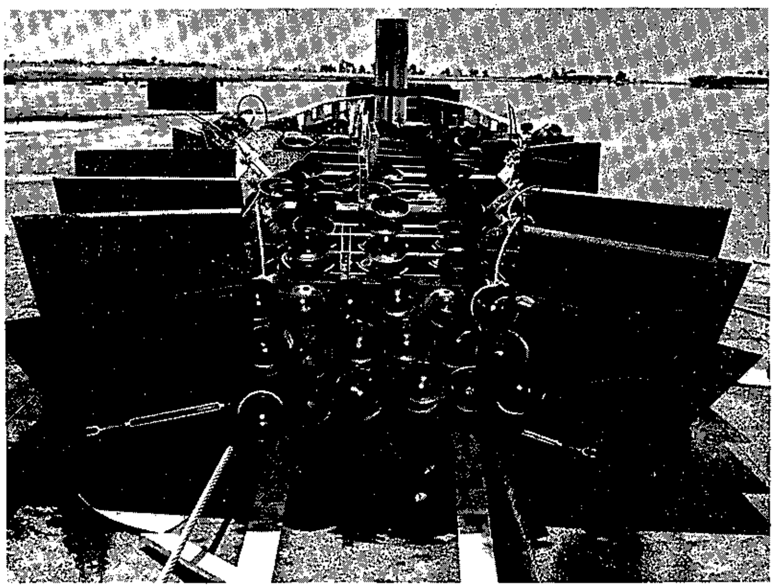


Figure 22

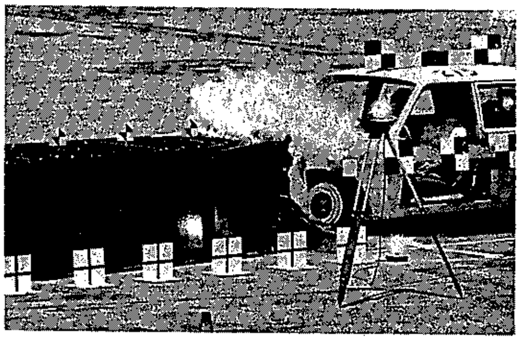
Figure 23

Instrumentation - Description and Results: Instrumentation used for Test 215 was similar to that for Tests 213 and 214. In addition to the FHWA system, there were six channels of data transmitted through a Visicorder Oscillograph. However, this did not produce usable results. This data included results from load cells on the two 7/8 inch cables and four pressure transducers in selected cartridges. See Exhibits 9 and 10 for the locations of the instrumentation.

The maximum compressive stress in the bridge approach guardrail tubular members was 4500 psi. Maximum lap belt load for the dummy driver was 513 lbs.; maximum load on the dummy's chest was 470 lbs. See the Appendix for a tabulation of these values for all the tests.

The accelerometers used for Test 215, all part of the FM Telemetry transmission system, had an unusually large amount of noise which was not eliminated with a 100 Hz filter. Since the test vehicle rolled over, the significance of the accelerometer records was even more questionable. The peak vehicular accelerations were 10-12 G's in the longitudinal direction (see Appendix, Plates A1 and A2). The highest 50 ms average vehicle deceleration (longitudinal) was 7.0 G's (average of two accelerometers). Thus, unrestrained vehicle occupants would have sustained minor to moderate injuries in most cases due to this longitudinal deceleration. Restrained occupants would probably have sustained little or no injuries due to this magnitude of longitudinal deceleration. The peak longitudinal deceleration for the dummy was more than 25 G's; the lateral and vertical decelerations were 10-12 G's for the dummy (see Plates A3, A4, A5 in the Appendix). These decelerations were sustained for relatively short 5 ms periods. The data traces had too much noise to show any clear-cut pulse shape or well defined peaks.

PLATE 6



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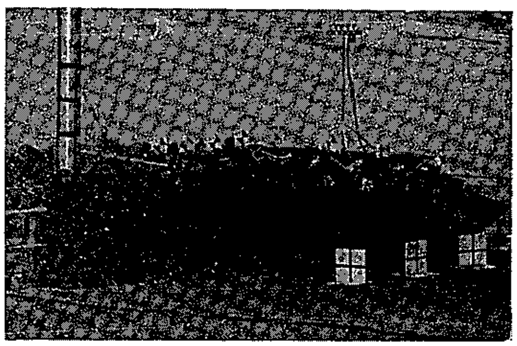
+ 0.44 Sec.



I + 2.58 Sec.

Test No.	215
Date	7-16-69
Vehicle	1968 Dodge[1]
Vehicle Weight (W/Dummy and Instrumentation)	4690 Lbs.
Impact Velocity	57.5 mph
Impact Angle	Head-on
Dummy Restraint	Lap belt

Barrier Depth	19.5 Ft.
No. of Water-Filled Cells	126
Permanent Displacement of Barrier Nose	9.3 Ft.
Deceleration Distance-Passenger Compartment	-
Maximum Vehicular Deformation	20 In.
Passenger Compartment Deceleration (Highest 50 ms avg. - accelerometer)	7.0 G's (long.)
Vehicle Average Deceleration-Calculated	Rolled

1 Left front door removed.

Test 216

Barrier Description: Modifications to the barrier used for Test 215 included cutting off the lower six inches of all the fender panels and cutting the lower rear corner of the panels on a diagonal to eliminate penetration of these trailing corners into the runway as occurred during Test 215 (see Figures 24 and 25, below). Also, metallic shoes (or skids) were added to the lower edge of interior panels, heavier hinges were used to attach the fender panels to the diaphragms, and all the evaporation flaps were removed to lessen, at least to some extent, the lateral discharge of the water and danger of loss of telemetry signal.

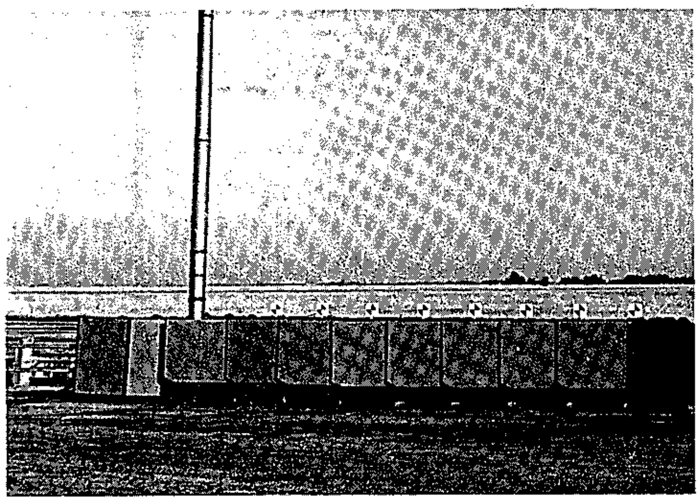


Figure 24

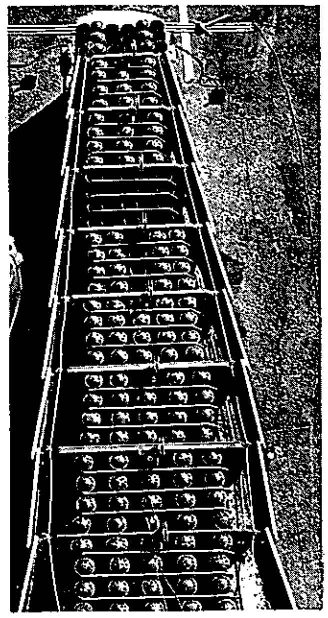


Figure 25

Results: Plate 7, page 35, contains a summary of the test results. A 4690 lb. 1968 Dodge impacted the barrier headon at a speed of 61.8 mph. Deceleration of the impacting vehicle was relatively smooth and the vehicle remained stable. Vehicle rise was a little more than 1'.

The maximum crush of the vehicle forestructure was 20 inches and occurred at the center of the vehicle (see Exhibit 8 and Figure 26, below). Buckling of the car body was indicated by a crimp in the roof over the door post on both sides of the car. The engine deflected the metal firewall back 1-2 inches. Steering wheel deformation was 1-1/4 inches. The steering column collapsed 2.9 inches. (There were collapsible steering columns in the 1968 Dodges used for Tests 215 through 218; however, there was no measurable collapse of them except in the vehicle used for this test).

Figure 26

No barrier components were dislodged. Fender panels on the left side of the first three modules were scarred. Bottoms and/or top inserts were blown out of 16 water cells. The shear pins on the front secondary cables were sheared off. The barrier as a whole was translated straight back with negligible lateral movement or "buckling". Maximum vehicular displacement of the barrier was 16.3 feet but the permanent displacement of the barrier nose was only 10.7 feet (see Figure 27, below).

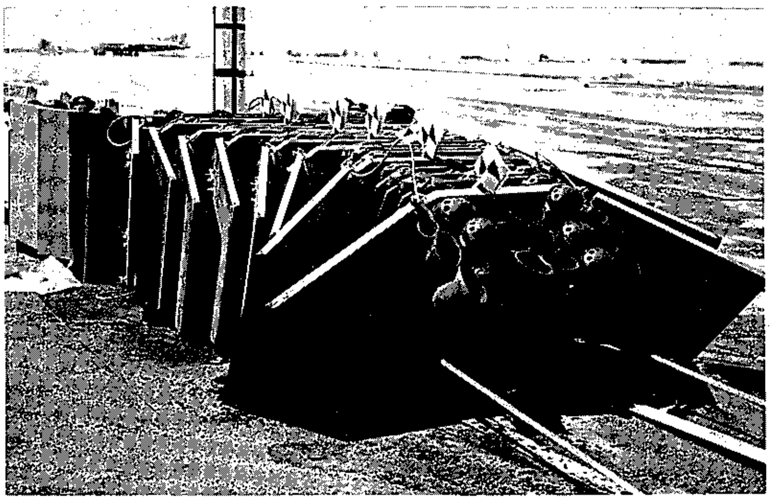


Figure 27

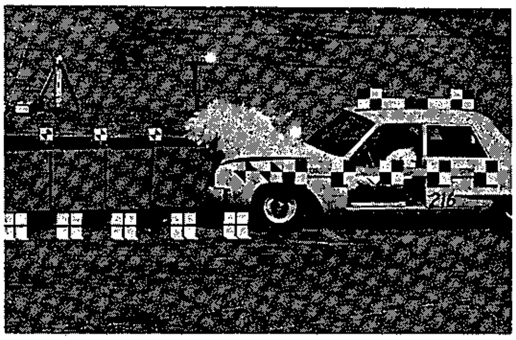
Instrumentation - Description and Results: Instrumentation was nearly identical to that used for Test 215 (see Exhibits 9 and 10).

The maximum pressure transducer reading from the cartridges was 110 psi. The maximum loads on the two 7/8 inch wire ropes were 14,750 lbs.-left, and 18,750 lbs.-right. The bridge approach guardrail experienced compressive stresses from 3060 psi-bottom left, to 12,200 psi-top left. Lap belt loads up to 533 lbs. were measured for the dummy driver along with a maximum chest load of 530 lbs. See the Appendix for a tabulation of the values from all tests.

The accelerometer records for Test 216 showed a great deal of high frequency noise which was not eliminated with the 100 Hz filter so lines were faired in through the unfiltered traces and adjusted as required after comparing the area under the faired curve with the impact velocity. (Because the vehicle was stopped, these values should agree.) The traces for longitudinal acceleration of the vehicle and dummy showed the main pulse shape quite clearly (see Plates A7 and A8 in the Appendix). The lateral and vertical dummy traces were more obscured by the noise (see Plates A9 and A10). The longitudinal vehicle trace showed three distinct peaks sustained for 5-10 ms. The highest 50 ms average vehicle deceleration (longitudinal) was 9.8 G's. These magnitudes and the general shape of the curve are in excellent agreement with that reported by TTI for a 64 mph headon impact of a 4650 lb. vehicle.[3] Thus, moderate to severe injuries would be sustained by unrestrained vehicle occupants in most cases. Little or no injury would be sustained by restrained vehicle occupants. Plate A7 in the Appendix also contains the predicted vehicle CG deceleration as supplied by the barrier developer. The longitudinal dummy trace had a shape very similar to that for the vehicle except the peaks were higher (above 14 G's for 5-10 ms). The first dummy peak occurred about 25 milliseconds after the first vehicle peak, but the later peaks occurred about the same time, presumably after the dummy was positioned against the seat belt or vehicle interior. The lateral dummy trace was somewhat erratic; however, it appears as though the peaks coincide with the longitudinal vehicle peaks.

The vertical dummy trace is similar in shape to the longitudinal dummy trace but with mostly lower peaks (8-12 G's). This reflects the probability that the main motion of the dummy had strong components in both the vertical and longitudinal direction as it was decelerated along a diagonal path.

PLATE 7



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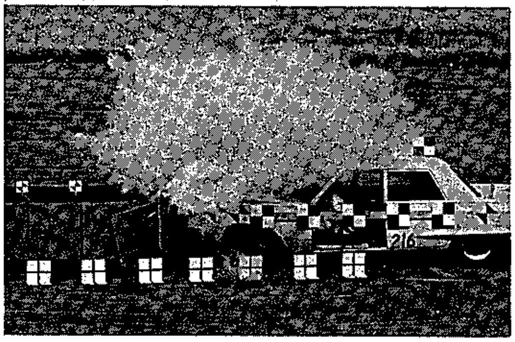

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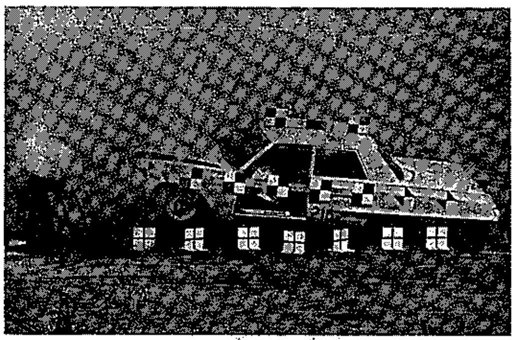

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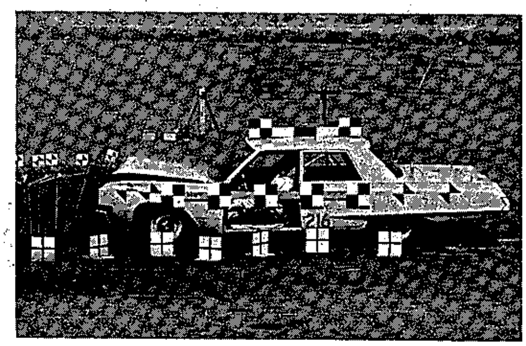


I + 2.73 Sec.

Barrier Depth	19.5 Ft.	Test No.	216
No. of Water-Filled Cells	126	Date	9-3-69
Permanent Displacement of Barrier Nose	10.7 Ft.	Vehicle	1968 Dodge[1]
Deceleration Distance-Passenger Compartment	18.0 Ft.	Vehicle Weight	4690 Lbs.
Maximum Vehicular Deformation	20 In.	(W/Dummy and Instrumentation)	
Passenger Compartment Deceleration	9.8 G's	Impact Velocity	61.8 mph
(Highest 50 ms avg. - accelerometer)	(long.)	Impact Angle	Head-on
Vehicle Average Deceleration-Calculated	7.1 G's	Dummy Restraint	Lap belt

1 Left front door removed.

Test 217

Barrier Description: The test barrier was the same as that used for Test 216.

Results: Plate 8, page 39, contains a summary of the test results. A 4760 lb. 1968 Dodge impacted along the side of the barrier ten feet behind the barrier nose at a speed of 57.0 mph and an angle of 9°. After the vehicle struck the barrier, it was slightly redirected by the barrier fender panels. However, significant redirection was not achieved until the solid resistance of the bridge approach guardrail was utilized. There was virtually no rise of the vehicle forestructure. The right front side of the car was severely crushed; there was no crush on the left side. (See Figure 28, below, and Exhibit 8). The right front door was damaged and jammed and the right door post was partially torn loose at the roof connection. The right side of the hood cracked the windshield. Near the end of the collision, the right rear quarter panel of the car slapped the barrier. This damaged the right rear fender and the right end of the rear bumper. A crimp in the roof over the door posts was sustained on both sides of the car; the radiator was buckled back toward the engine on the right side. The steering wheel had a slight deformation but the steering column did not collapse.

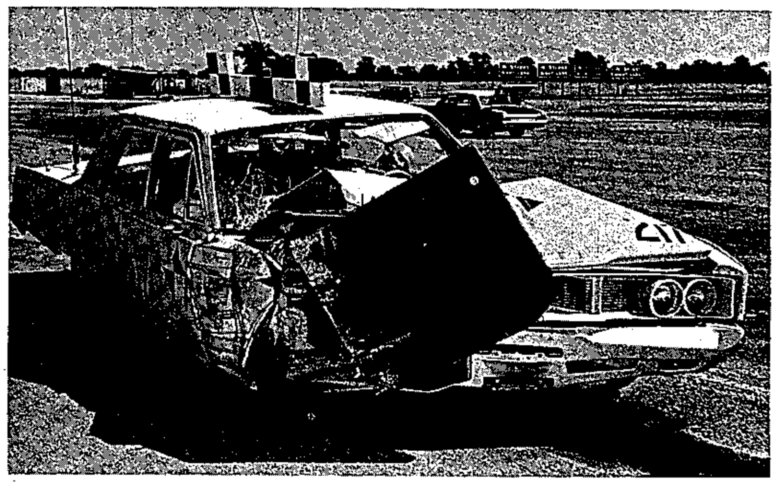


Figure 28

Several fender panels were torn off the barrier on the left side, mainly due to hinge failures. Two panels were thrown 8'-0" beyond the final position of the car and two panels were lodged in the crushed front end of the car. The five cells on the left side of the bridge approach guardrail were all torn off and scattered along the path of the car. Shear pins in the secondary cables sheared off. Permanent displacement of the barrier nose was 1.5 feet (see Figures 29 and 30, below).

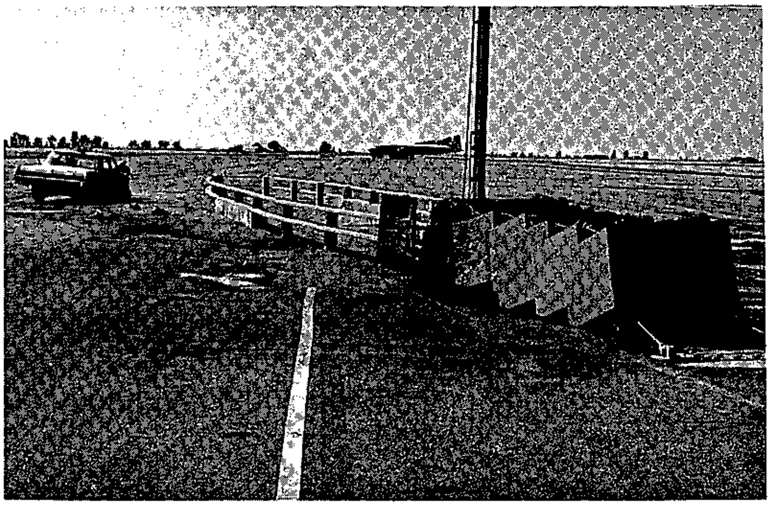


Figure 29

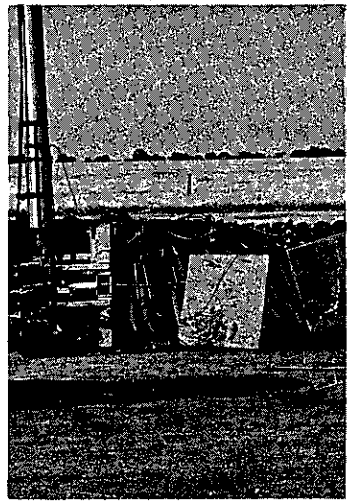


Figure 30

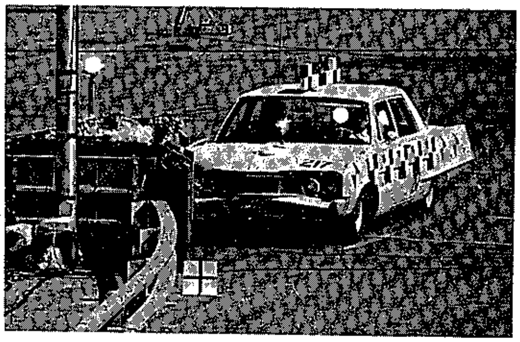
Instrumentation - Description and Results: The instrumentation was the same as that used in Test 213, i.e. the FHWA System plus the six extra channels recorded directly on the visicorder oscillograph. See Exhibits 11 and 12 for the type and location of this instrumentation.

The maximum pressure transducer reading was 50 psi. The maximum loads on the two 7/8 inch cables were 14,300 lbs. -left and 11,500 lbs.-right. The bridge approach guardrails sustained compressive stresses from 3540 psi-top right to 9850 psi-bottom left. Lap belt and chest loads on the dummy were not measured for this test. See the Appendix for a tabulation of values from all tests.

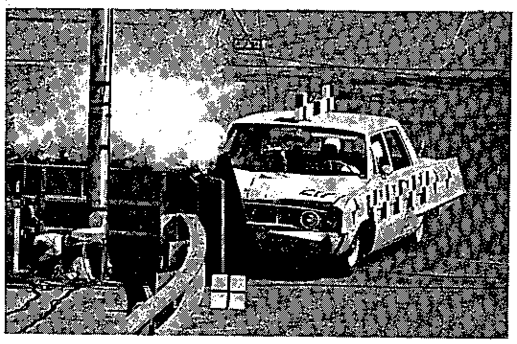
Two accelerometer traces were produced in Test 217 for both the longitudinal and lateral motions of the vehicle (4 total) and were filtered at 100 Hz (see Plate A11, A12, A13 and A14 in the Appendix). The two longitudinal traces were very similar with thin peaks above 15 G's. The highest 50 ms average vehicle passenger compartment deceleration was 8.4 G's (average of two accelerometers). The two lateral traces were also similar. The highest 50 ms vehicle passenger compartment average (average of two accelerometers) was 5.2 G's. Thus, unrestrained vehicular occupants would have sustained moderate to severe injuries in most cases. If a lap belt were used, no more than moderate injury would usually occur. Fully restrained occupants would have sustained little or no injury. The lateral traces were similar in shape to the longitudinal ones. The highest peaks (9 G's for 5 ms) occurred on all four traces at about 190 milliseconds after impact. At 430 milliseconds after impact, all four records show evidence of a deceleration pulse due to the rear of the car slapping the barrier.

The filtered traces for the longitudinal and lateral dummy motions appear to be distorted by the noise; they show large, somewhat erratic peaks (Plates A15 and A16, Appendix).

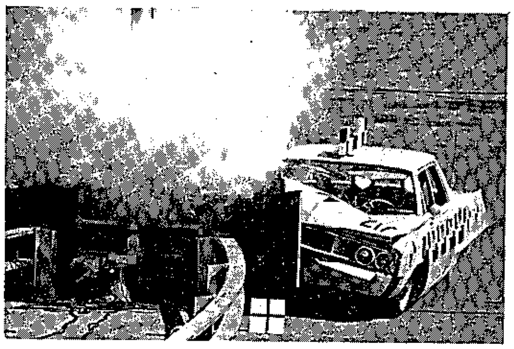
PLATE 8



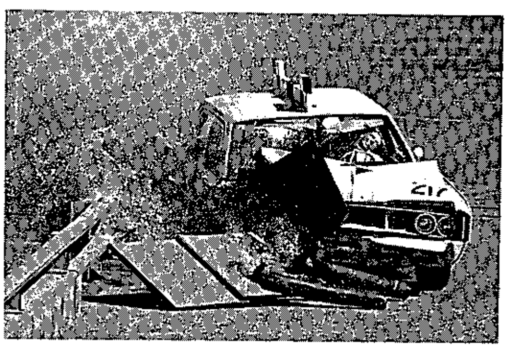
Impact + 0.05 Sec.



I + 0.14 Sec.



I + 0.23 Sec.



I + 0.62 Sec.

Barrier Depth	19.5 Ft.	Test No.	217
No. of Water-Filled Cells	126	Date	9-25-69
Permanent Displacement of Barrier Nose	1.5 Ft.	Vehicle	1968 Dodge
Deceleration Distance-Passenger Compartment	-	Vehicle Weight	4760 Lbs.
Maximum Vehicular Deformation	-	(W/Dummy and Instrumentation)	
Passenger Compartment Deceleration	8.4 G's	Impact Velocity	57.0 mph
(Highest 50 ms avg. - accelerometer)	(long.)	Impact Angle	9° (side)
Vehicle Average Deceleration-Calculated	Redirected	Dummy Restraint	Lap belt

Test 218

Barrier Description: The test barrier was the same as that used for Test 216 and 217.

Results: Plate 9, page 43, contains a summary of the test results. A 4760 lb. 1968 Dodge impacted the nose of the barrier at an angle of 8° and a speed of 59.2 mph. The vehicle struck the barrier, rotated until it was nearly on line with the barrier axis, and continued to a stop in a manner similar to that of Test 216 (62 mph headon impact). The crush in the vehicle forestructure formed an arc (plan view) with least crush at the fenders. Maximum crush at the center was 19 inches (see Figure 31, below, and Exhibit 8). Once again, a crimp was noted in the roof over the door posts on both sides of the car. The left front door was jammed and the radiator buckled back towards the engine. Vehicle rise was 1'-4".

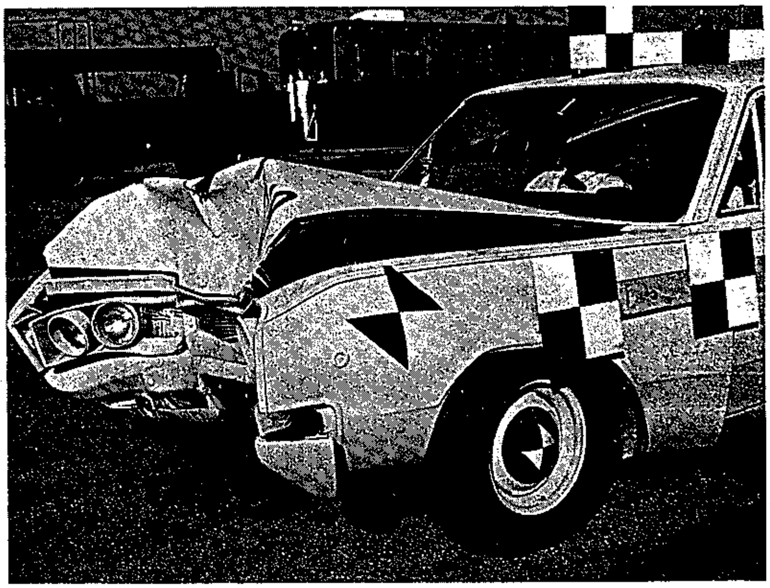


Figure 31

Maximum vehicular penetration was 15.3 feet and permanent displacement of the barrier nose was 11.7 feet. There was delamination and splitting of some of the interior panels and diaphragms, bent and broken hinges, and gouging of some of the fender panels; however, no parts became detached from the barrier (see Figure 32, below).

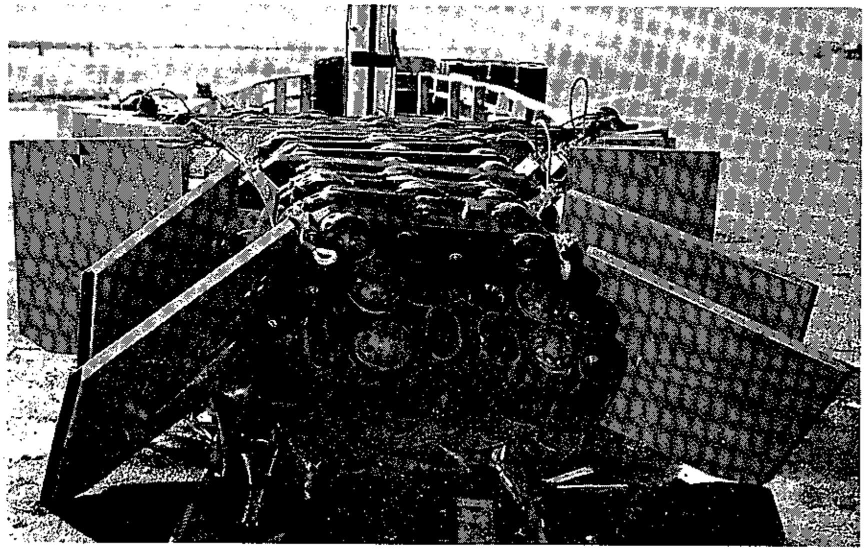


Figure 32

Instrumentation - Description and Results: The FHWA instrumentation system was used in addition to nine channels of information that were transmitted through a hardwire system to a second magnetic tape recorder (see Exhibits 11 and 12).

The maximum pressure transducer reading from the cells was 64.0 psi. The maximum loads on the two 7/8 inch cables were 20,900 lbs. left, and 5450 lbs.-right. The bridge approach guardrails sustained compressive stresses from 4800 psi bottom left to 12,000 psi top right. The lap belt load was not measured; the maximum chest load on the dummy was 175 lbs.

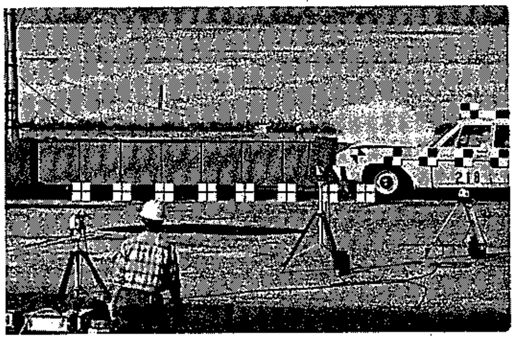
Nine accelerometer records, filtered at 100 Hertz, were obtained for Test 218; the results were relatively free of noise (Plates A17 through A26). Three longitudinal vehicle deceleration records were obtained; two were transmitted via FM Telemetry and one by a hardwire system. All showed three distinct peaks greater than 13 G's (5 ms duration) and were identical in shape. All had similar values of deceleration except that the accelerometer mounted at the center of gravity of the vehicle had a few thin spikes above the main peaks, principally at the second main peak. The trace received through the hardwire system was almost identical in magnitude and shape to the corresponding trace from Test 216 except that the third main peak in Test 218 occurred about 40 milliseconds later. The average 50 ms vehicle passenger compartment deceleration (three accelerometers) was 10.2 G's. This magnitude of deceleration would cause moderate to severe injuries in most cases if the vehicle occupants were not fully restrained.

Three records of lateral vehicle motion were obtained from the same locations and by the same means of data transmission as the longitudinal vehicle records. These records were all similar. However, the one at the center of gravity of the vehicle had several thin noise spikes. Excluding the noise spikes (which don't show on the data transmitted by hardwire), the maximum values of deceleration were 3-4 G's for 10-15 millisecond durations. The fact that the vehicle impacted the nose of the barrier at an angle did not appear to cause large lateral decelerations. The lateral vehicle trace for Test 216 was poor and not worth comparing with those from Test 218.

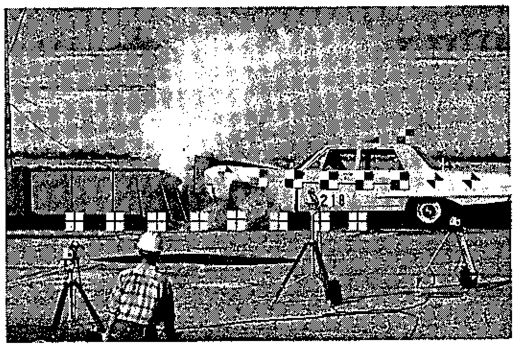
Accelerometer records were obtained for the motion of the chest of the driver dummy in the longitudinal, lateral, and vertical directions. The longitudinal record, only, was transmitted by hardwire. It had a shape very similar to the longitudinal vehicle records with two peaks exceeding 12 G's for as much as 30 ms. The first dummy peak lagged the vehicle peak by about 40 milliseconds; the other two peaks lagged about 20 milliseconds as the dummy apparently became snugly positioned against the interior of the vehicle. This record was quite similar in shape and magnitude to the longitudinal dummy record for Test 216 except that the third peak lagged 40 milliseconds in Test 218, and the Test 216 record had a few thin noise spikes which rose above the first and second main peaks.

The lateral dummy record of motion showed a thin 20 G spike (5 ms duration), three or four other thin spikes with magnitudes of 8 to 10 G's (also 5 ms duration), and low values elsewhere. The peaks occurred at the same time as the longitudinal dummy peaks but the shape of the two curves was totally dissimilar. The vertical dummy record of deceleration was similar to that for longitudinal motion except that the first vertical peak was opposite in direction to the second and third vertical peaks. Except for one thin (5 ms) 23 G spike, the second and third peaks (also 5 ms) were about 13 G's. If the second and third longitudinal and vertical peaks are resolved vectorially, the resultant is about 18-19 G's for each peak. The vertical dummy records for Tests 216 and 218 were similar at some points, but no similar clear-cut pulse shape was apparent for both tests.

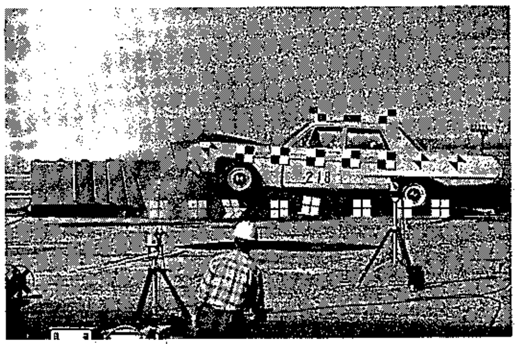
PLATE 9



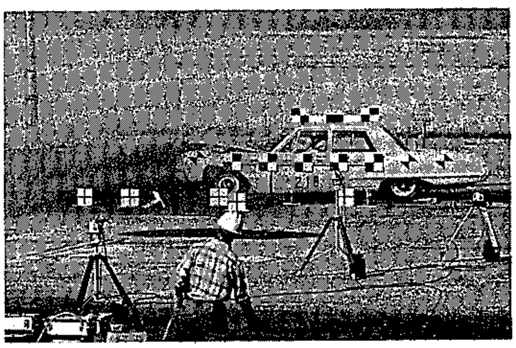
Impact + 0.04 Sec.



I + 0.13 Sec.



I + 0.31 Sec.



I + 1.30 Sec.

Barrier Depth	19.5 Ft.
No. of Water-Filled Cells	126
Permanent Displacement of Barrier Nose	11.7 Ft.
Deceleration Distance-Passenger Compartment	16.9 Ft.
Maximum Vehicular Deformation	20 In.
Passenger Compartment Deceleration	10.2 G's
(Highest 50 ms avg. - accelerometer)	(long.)
Vehicle Average Deceleration-Calculated	6.9 G's

Test No.	218
Date	11-12-69
Vehicle	1968 Dodge
Vehicle Weight	4760 Lbs.
(W/Dummy and Instrumentation)	
Impact Velocity	59.2 mph
Impact Angle	8° (nose)
Dummy Restraint	Lap belt

VI. REFERENCES

1. "Engineering Evaluation of Water-Filled Plastic Cells in Fixed Barrier Automobile Impacts", Report No. RSCB-2, Department of Mechanical Engineering, Brigham Young University, January 5, 1968.

2. Nordlin, E. F., Woodstrom, J. H., and Doty, R. N., "Dynamic Tests of an Energy Absorbing Barrier Employing Steel Drums, Series XXII", California Division of Highways, October 1970.

3. Hayes, G. G., Ivey, D. L., and Hirsch, T. J., "Performance of the 'Hi-dro Cushion' Vehicle Impact Attenuator", Technical Memorandum 505-11; Texas Transportation Institute; August, 1970.

4. Nordlin, E. F., Woodstrom, J. H., and Hackett, R. P., "Dynamic Tests of the California Type 20 Bridge Barrier Rail, Series XXIII", California Division of Highways; October, 1970.

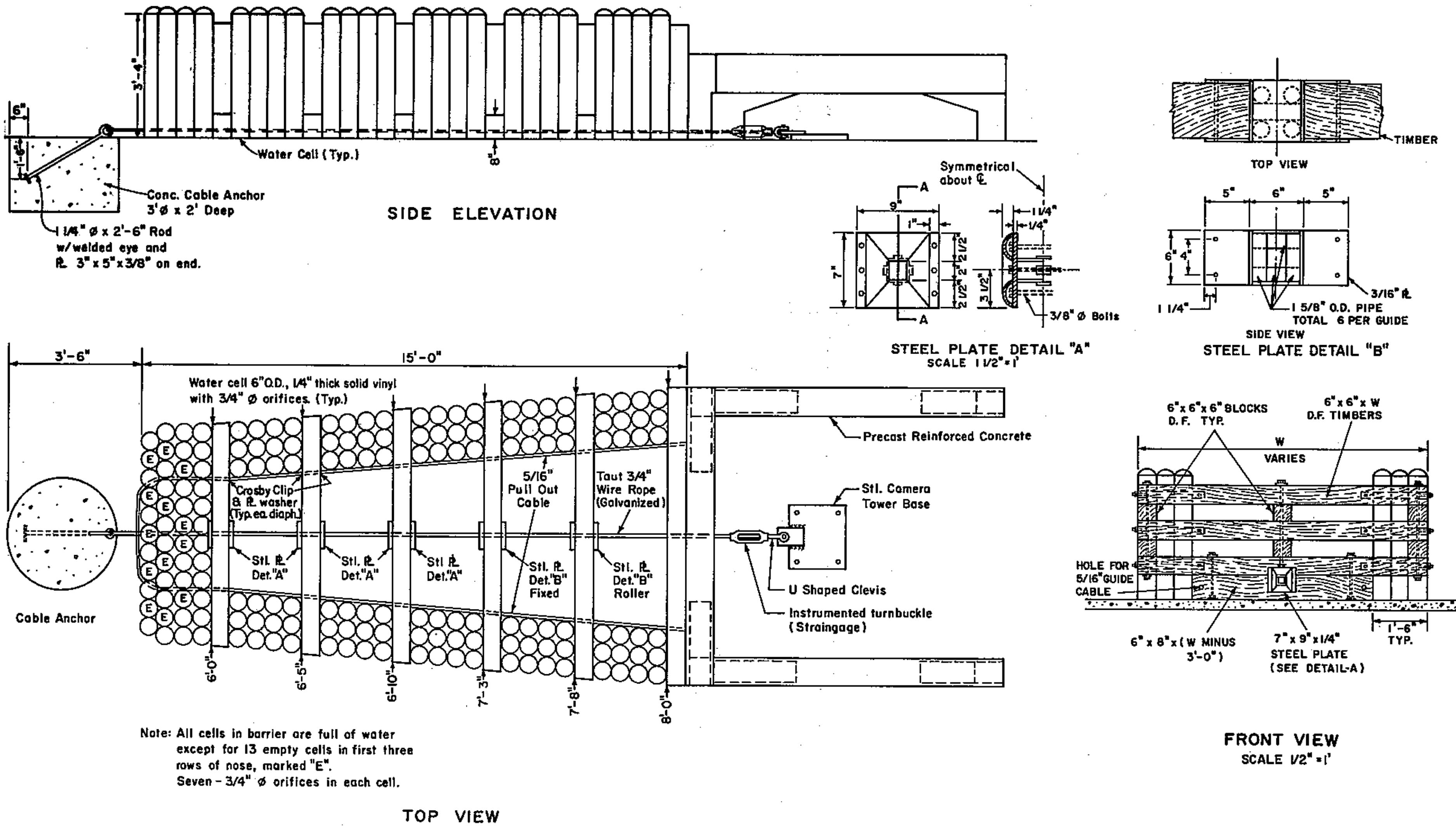
5. Nordlin, E. F. Field, R. N., and Prysock, R. H., "Dynamic Full Scale Impact Tests of Double Blocked-out Metal Beam Barriers and Metal Beam Guard Railing, Series X"; California Division of Highways; February, 1965.

6. Nordlin, E. F., Ames, W. H., Kubel, L. G., and Chow, W., "Evaluation of a Telemetry System for Use in Vehicle-Barrier Impact Tests", State of California, Department of Public Works, Division of Highways, Materials and Research Department, Research Report No. 636405-1 dated July 1969.

7. "Development of a Hydraulic-Plastic Barrier for Impact-Energy Absorption", BPR-DOT Contract No. FH-11-6909 Final Report, Department of Mechanical Engineering, Brigham Young University.

8. "Federal Motor Vehicle Safety Standards", National Highway Safety Bureau, U. S. Dept. of Transportation, with amendments and interpretations through August 6, 1968.

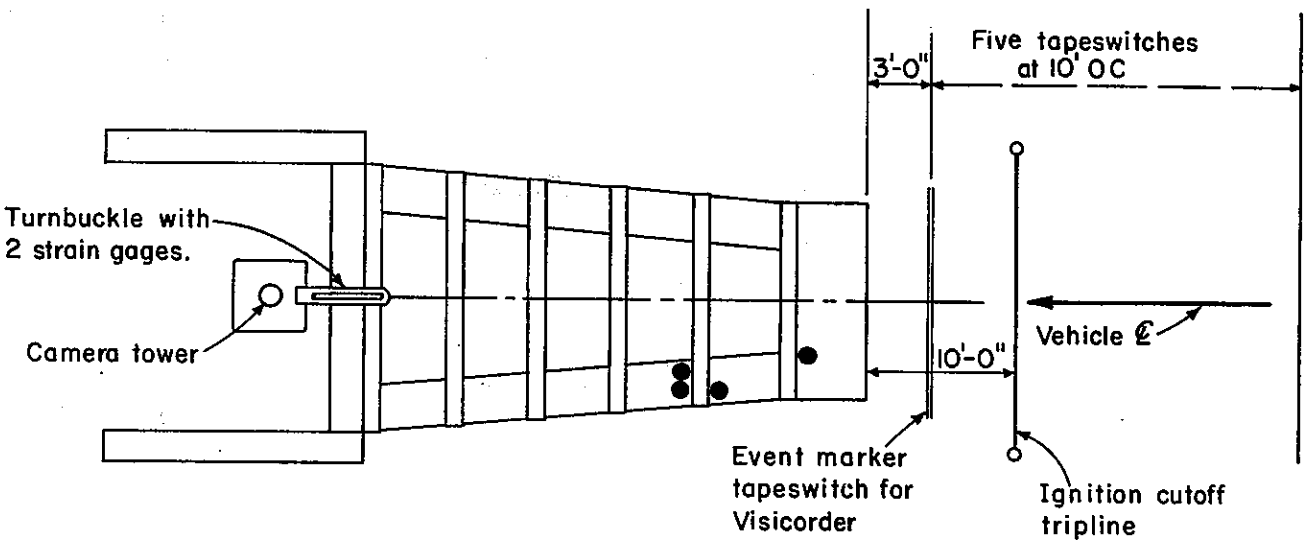
EXHIBIT 1



TEST #211, 212 NOSE
HI-DRO CUSHION CELL BARRIER

EXHIBIT 2

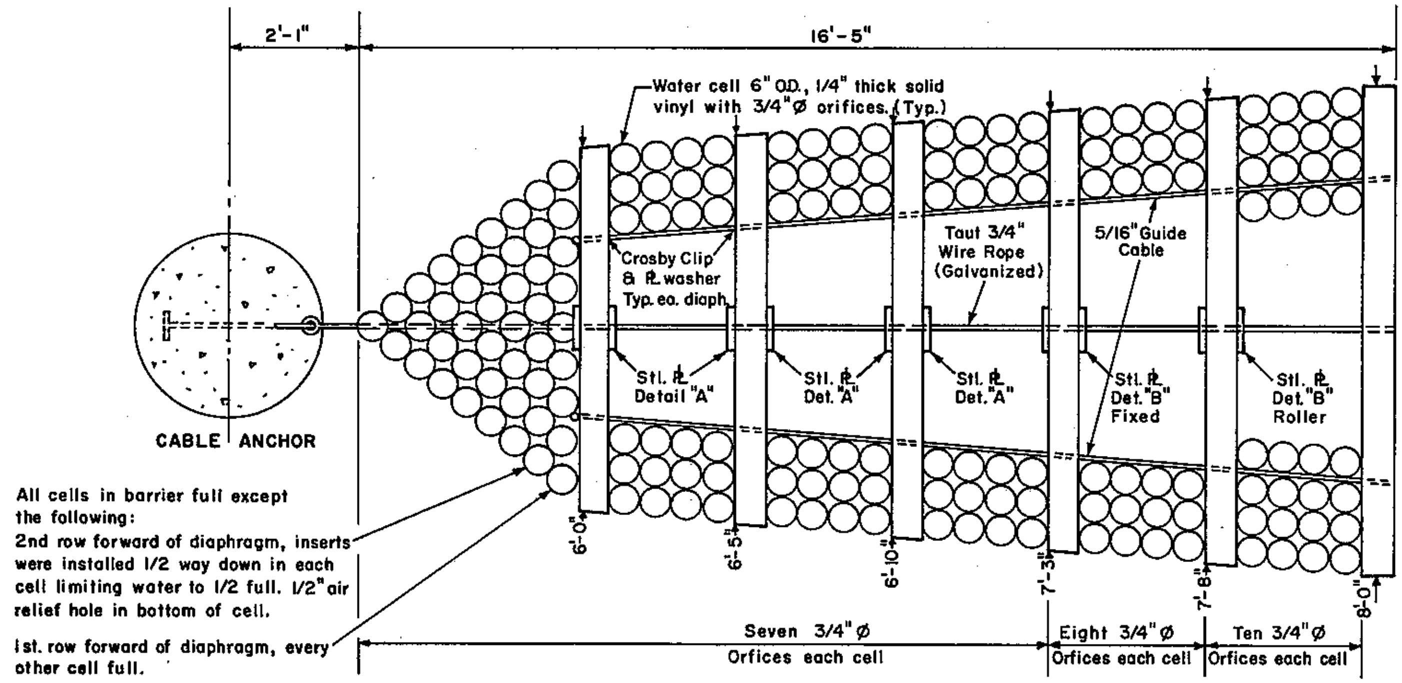
BARRIER INSTRUMENTATION
TEST 211 AND 212



LEGEND:

● = Pressure transducer in water cells.

EXHIBIT 3



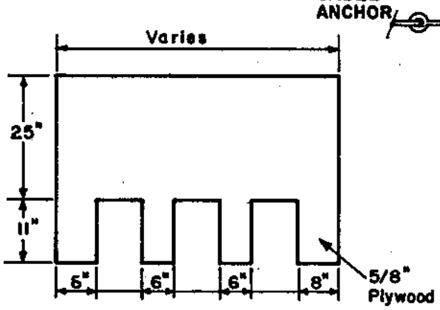
TOP VIEW
TEST # 213 NOSE

HI-DRO CUSHION CELL BARRIER

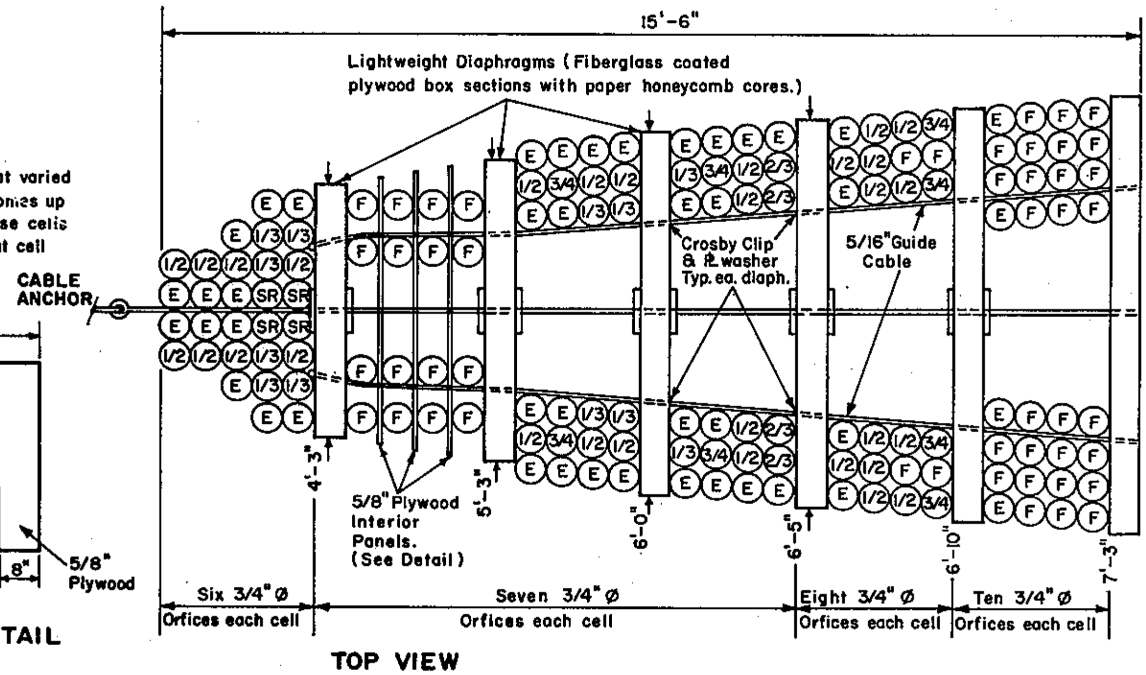
LEGEND

E = Empty
F = Full
SR = Structural Ring only.

Note: Inserts placed in cells at varied depths so water always comes up to top of cell except in nose cells where water is centered at cell mid-height.



INTERIOR PANEL DETAIL



TOP VIEW
TEST # 214 NOSE

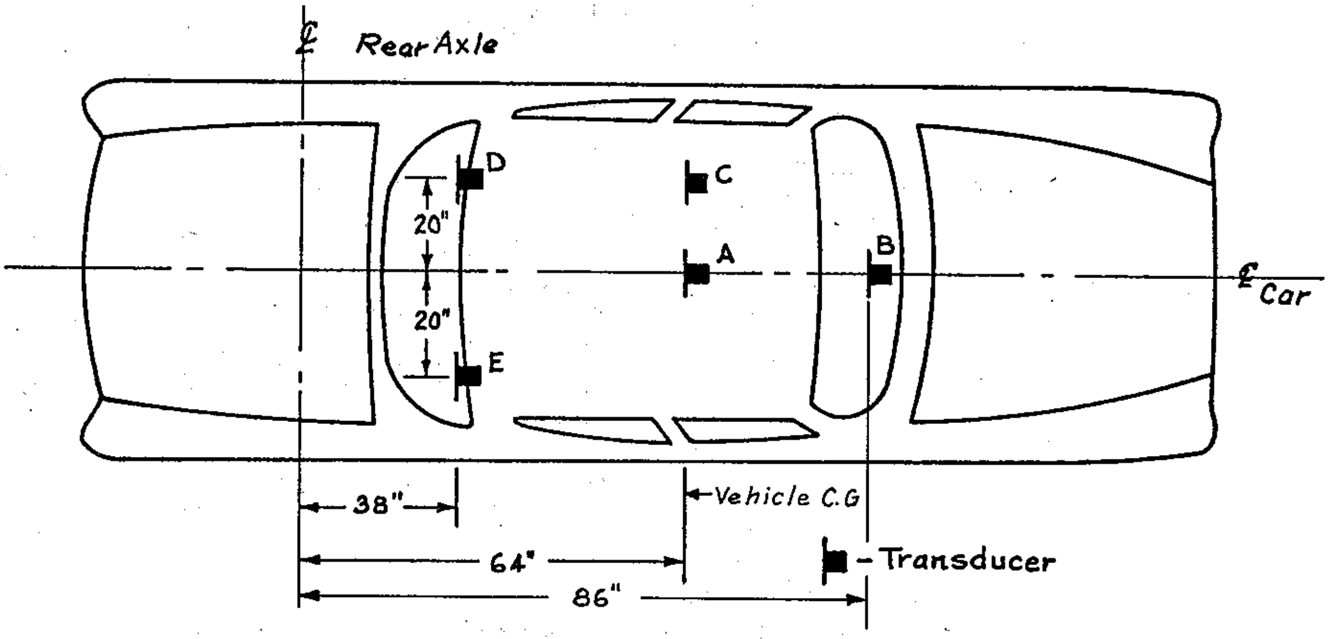
NOTE: FOR OTHER DETAILS, SEE BARRIER DRAWINGS FOR TESTS # 211, 212.

EXHIBIT 4

CALIFORNIA DIVISION OF HIGHWAYS

VEHICLE INSTRUMENTATION

WATER-FILLED CELL ENERGY ATTENUATOR TESTS



Test #213

CHANNEL NO.	LOCATION[1]	DESCRIPTION
1	C	50 "G" longitudinal accelerometer
2	D	50 "G" longitudinal accelerometer (malfunction)
3	A	100 "G" longitudinal accelerometer (malfunction)
4	B	100 "G" longitudinal accelerometer
5	E	50 "G" longitudinal accelerometer (malfunction)
6	C	Lap belt tension transducer
7	C	Shoulder harness tension transducer

Test #214

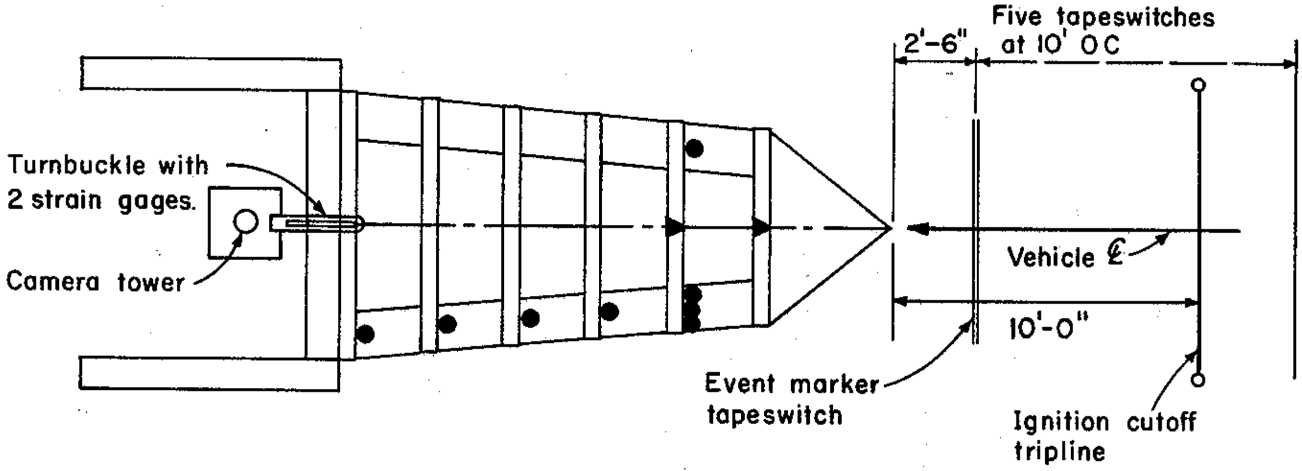
CHANNEL NO.	LOCATION[1]	DESCRIPTION
1	C	100 "G" longitudinal accelerometer
2	D	50 "G" longitudinal accelerometer
3	A	100 "G" longitudinal accelerometer
4	B	50 "G" longitudinal accelerometer
5	E	50 "G" longitudinal accelerometer
6	C	Lap belt tension transducer
7	C	Shoulder harness tension transducer

Notes:

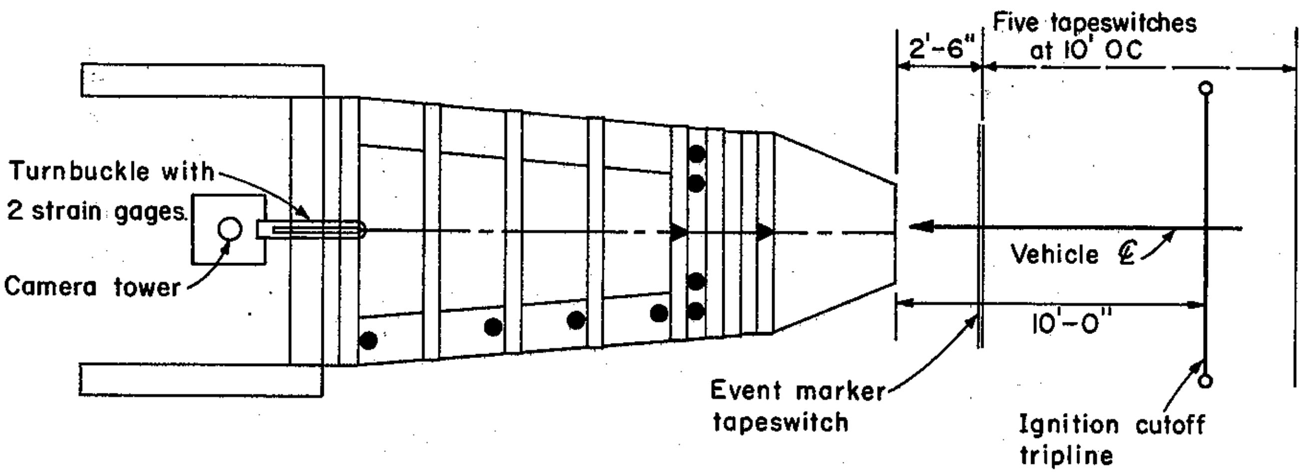
[1] A, B, D, and E on vehicle floor; C in dummy's chest cavity.

EXHIBIT 5

BARRIER INSTRUMENTATION
TEST 213 AND 214



TEST 213

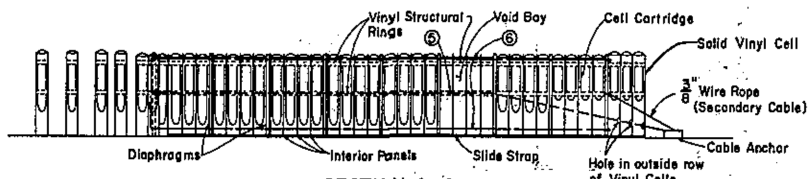


TEST 214

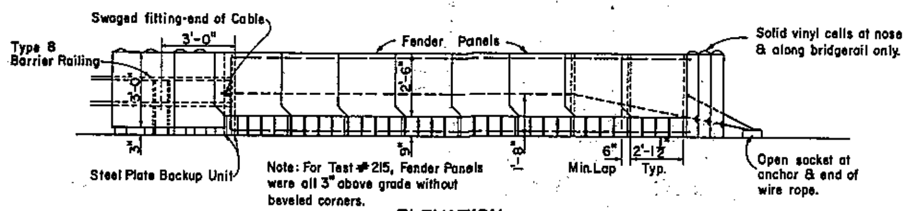
LEGEND:

▶ = Accelerometer

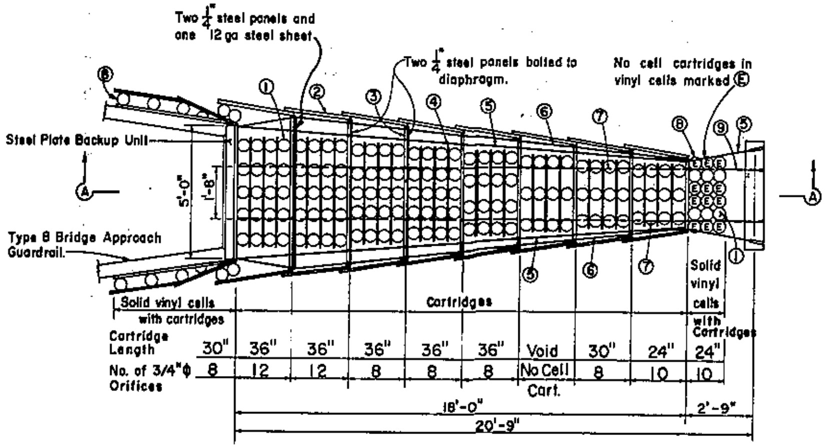
● = Pressure transducer in water cells.



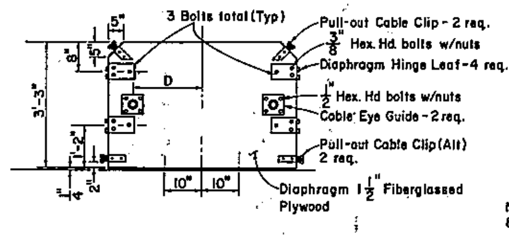
SECTION A-A
1/2" = 1'-0



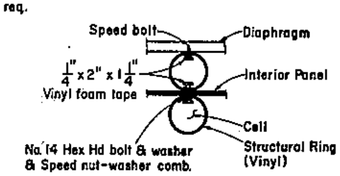
ELEVATION
1/2" = 1'-0"



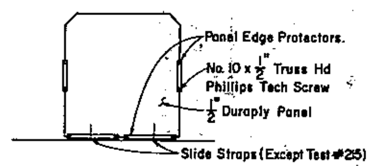
PLAN



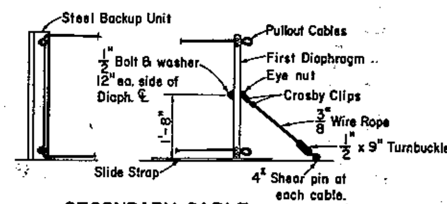
DIAPHRAGM - ELEVATION
3/4" = 1'-0"



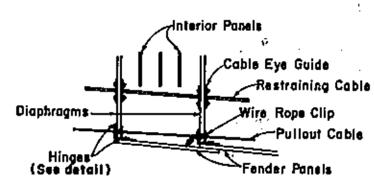
CELL-PLAN
No Scale



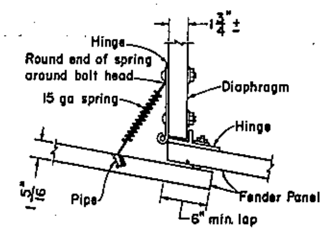
INTERIOR PANEL
3/4" = 1'-0"



SECONDARY CABLE
3/4" = 1'-0"



HINGE PLAN



HINGE DETAIL

LEGEND

① - Hi-Dro Cushion Cell Cartridge (Vinyl coated nylon fabric) 126 total.
② - Fender Panel - 1 1/4" fiberglassed plywood.
③ - Diaphragm - 1 1/2" fiberglassed plywood.
④ - Interior Panel - 1/2" duraply plywood.
⑤ - Restraining Cable - 7/8" wire rope.
⑥ - Pullout Cable - 3/8 wire rope.
⑦ Slide Straps - 4" x 1/4" steel straps (on ground)
⑧ Hi-Dro Cushion Cells - solid vinyl. (28 total)
⑨ Secondary Cable 3/8" wire rope with 4# shear pin.

BARRIER DETAILS - TEST NO. 215-218

EXHIBIT 7

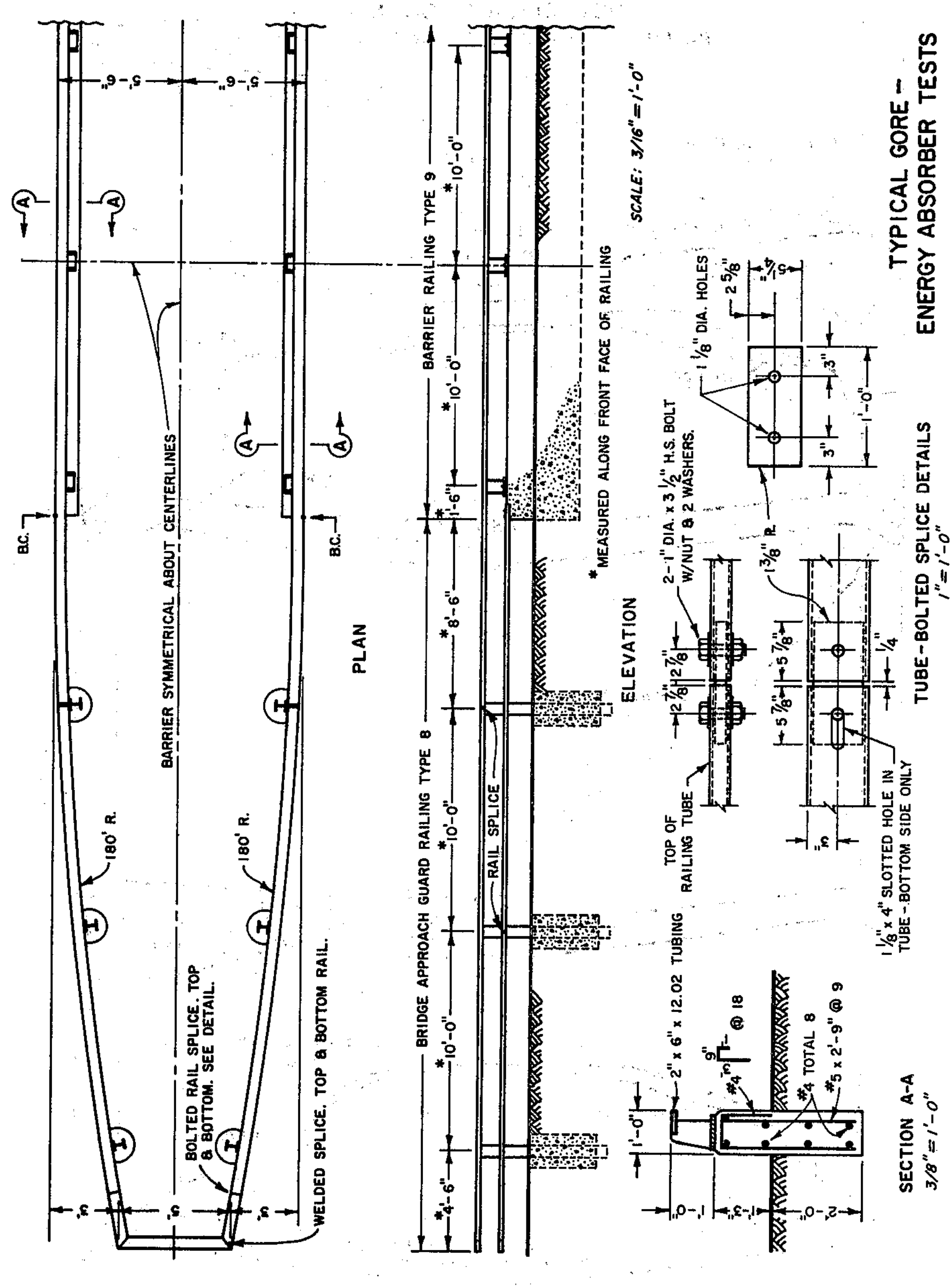
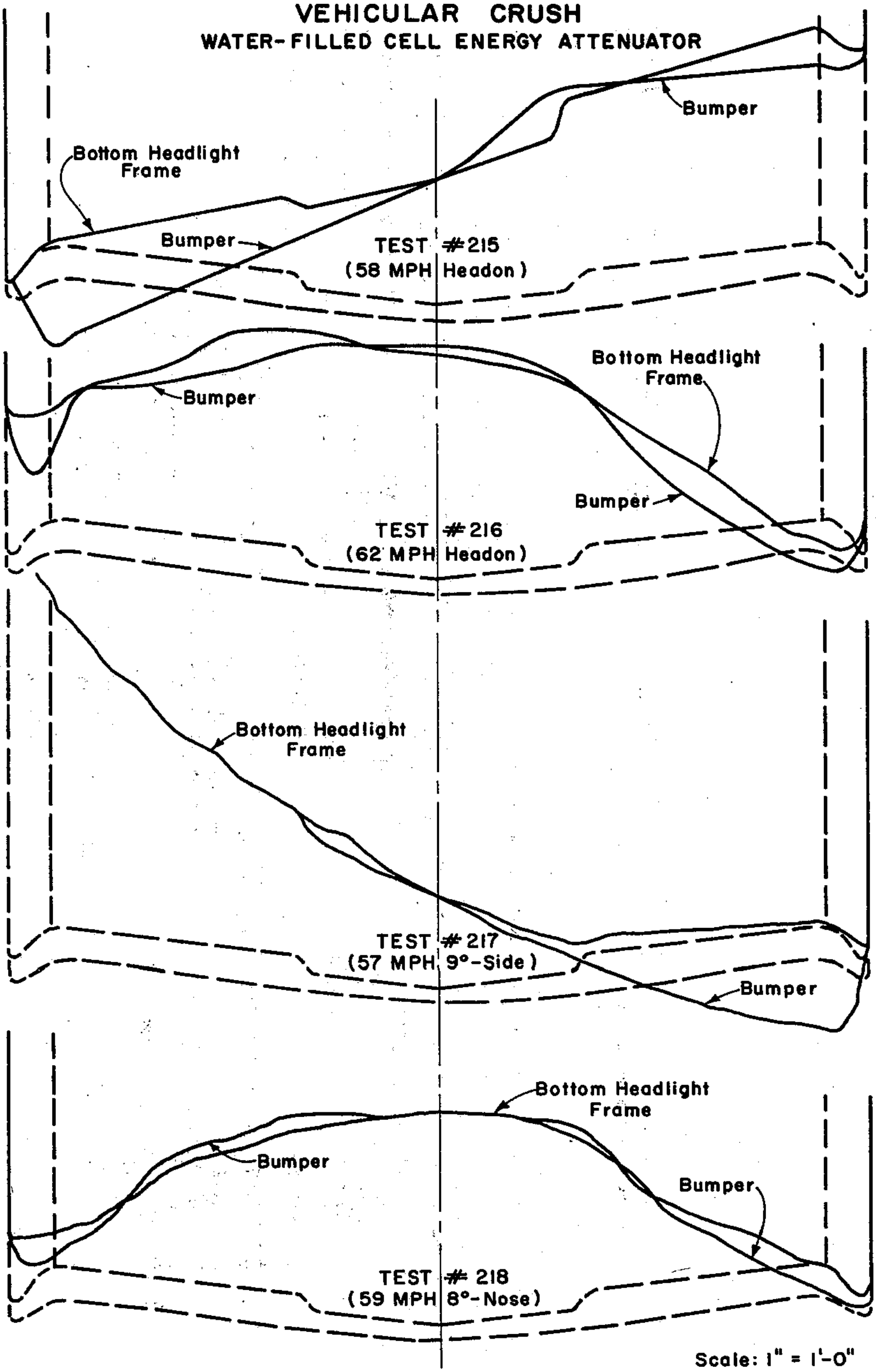

TYPICAL GORE – ENERGY ABSORBER TESTS
SCALE: 3/16"=1'-0"
PLAN
BARRIER SYMMETRICAL ABOUT CENTERLINES
5'-6"
5'-6"
B.C.
B.C.
180' R.
180' R.
BOLTED RAIL SPLICE, TOP & BOTTOM. SEE DETAIL.
WELDED SPLICE, TOP & BOTTOM RAIL.
3'
5'
3'
ELEVATION
BRIDGE APPROACH GUARD RAILING TYPE 8
BARRIER RAILING TYPE 9
*4'-6"
*10'-0"
*10'-0"
*8'-6"
*1'-6"
*10'-0"
*10'-0"
RAIL SPLICE
*MEASURED ALONG FRONT FACE OF RAILING
SECTION A-A
3/8"=1'-0"
2" x 6" x 12.02 TUBING
#4 @ 18
#4 TOTAL 8
#5 x 2'-9" @ 9
1'-0"
1'-0"
1'-3"
2'-0"
TUBE-BOLTED SPLICE DETAILS
1"=1'-0"
TOP OF RAILING TUBE
2-1" DIA. x 3 1/2" H.S. BOLT W/NUT & 2 WASHERS.
1 1/8" DIA. HOLES
1 3/8" R.
1 1/8" x 4" SLOTTED HOLE IN TUBE-BOTTOM SIDE ONLY
2 5/8"
1'-0"
3"
3"
5 7/8"
5 7/8"
1/4"
2 7/8"
2 7/8"

EXHIBIT 8

VEHICULAR CRUSH

WATER-FILLED CELL ENERGY ATTENUATOR



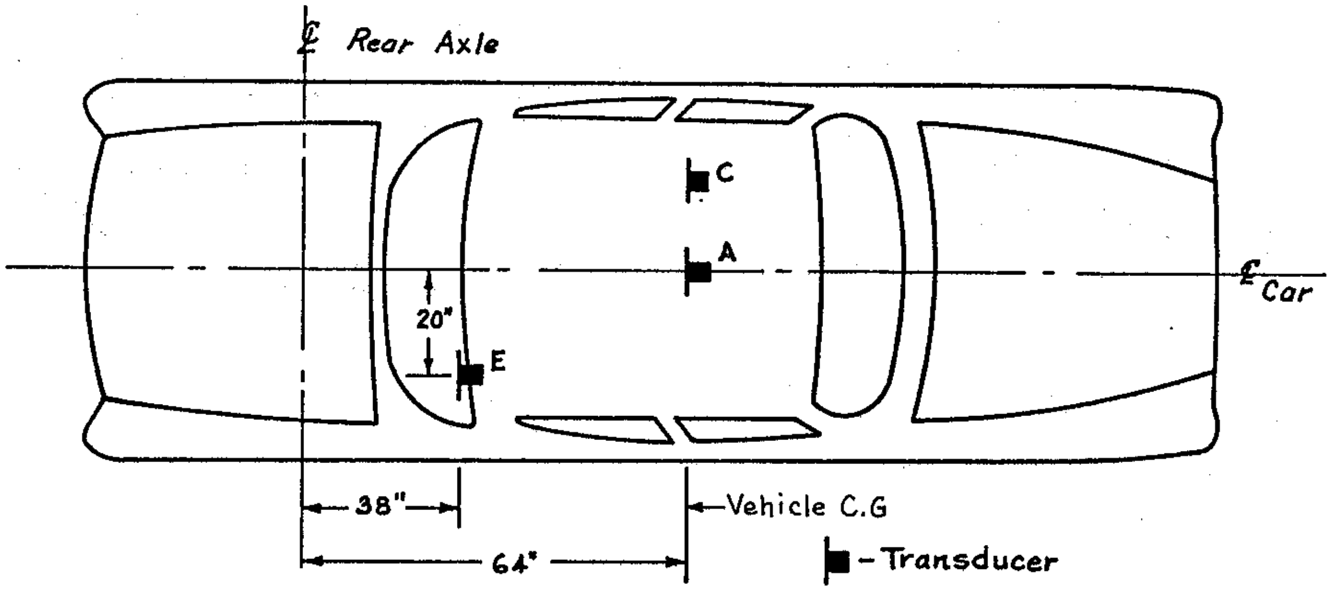
Scale: 1" = 1'-0"

EXHIBIT 9

CALIFORNIA DIVISION OF HIGHWAYS

VEHICLE INSTRUMENTATION

WATER-FILLED CELL ENERGY ATTENUATOR TESTS



Tests #215 & 216

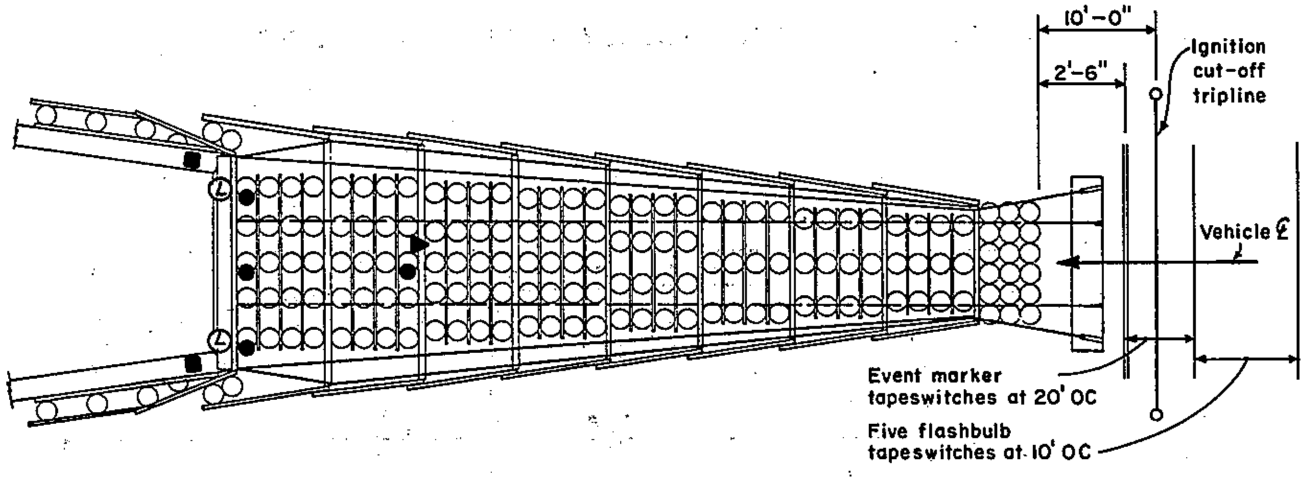
CHANNEL NO.	LOCATION[1]	DESCRIPTION
1	A	100 "G" longitudinal accelerometer
2	E	100 "G" longitudinal accelerometer
3	C	50 "G" longitudinal accelerometer
4	C	50 "G" lateral accelerometer
5	C	50 "G" vertical accelerometer
6	C	Force meter in dummy's chest
7	C	Lap belt tension transducer

Notes:

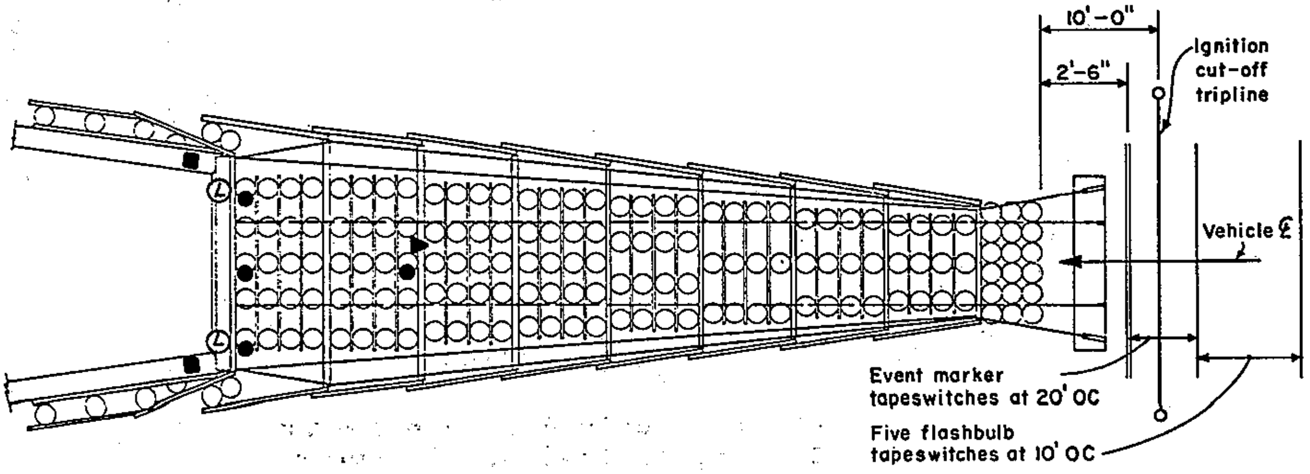
[1] A and E on vehicle floor; C on back of dummy's chest cavity.

EXHIBIT 10

BARRIER INSTRUMENTATION
TESTS 215 & 216



TEST 215



TEST 216

LEGEND:

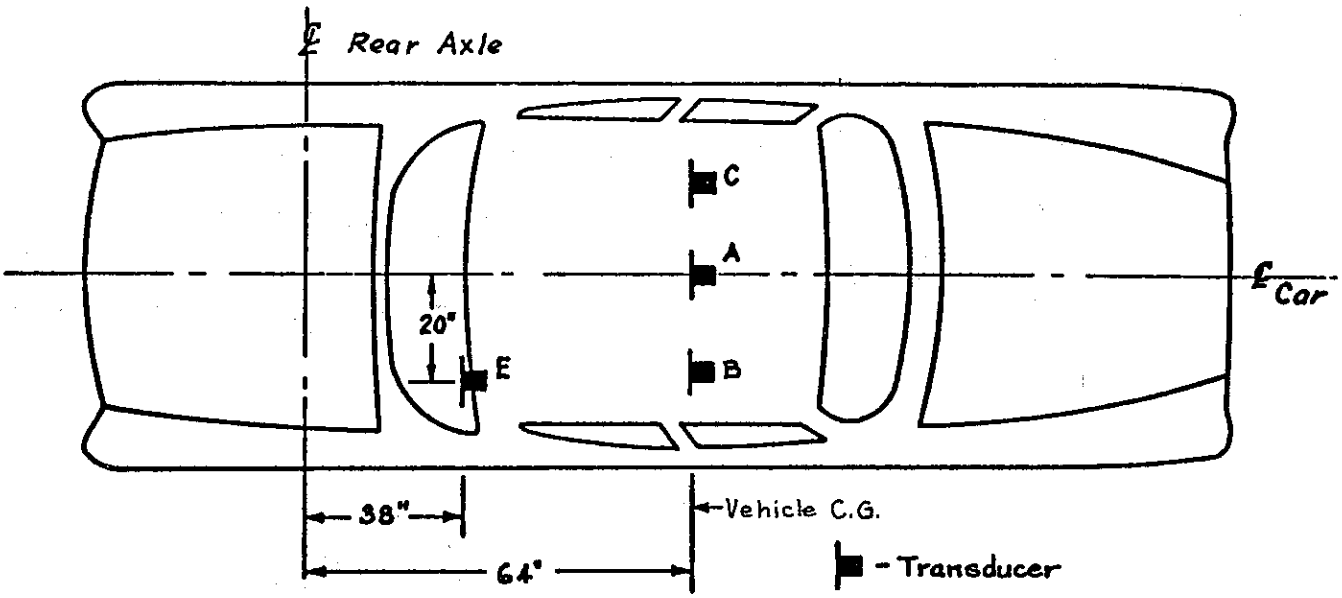
- ■ = Strain gage – on top of top and bottom bridgerails (Total 4)
- ● = Pressure transducer in water cells.
- Ⓛ = Load cell on main cables
- ▶ = Accelerometer.

EXHIBIT 11

CALIFORNIA DIVISION OF HIGHWAYS

VEHICLE INSTRUMENTATION

WATER-FILLED CELL ENERGY ATTENUATOR TESTS



Test #217

CHANNEL NO.	LOCATION[1]	DESCRIPTION[2]
1	A	100 "G" longitudinal accelerometer (T)
2	A	100 "G" lateral accelerometer (T)
3	E	100 "G" longitudinal accelerometer (T)
4	E	50 "G" lateral accelerometer (T)
5	C	50 "G" longitudinal accelerometer (T)
6	C	50 "G" lateral accelerometer (T)
7	C	50 "G" vertical accelerometer (T)

Test #218

1	A	100 "G" longitudinal accelerometer (T)
2	A	100 "G" lateral accelerometer (T)
3	E	100 "G" longitudinal accelerometer (T)
4	E	50 "G" lateral accelerometer (T)
5	C	50 "G" vertical accelerometer (T)
6	C	Force meter (in dummy's chest cavity)
7	C	50 "G" lateral accelerometer (T)
G	E	50 "G" lateral accelerometer (U)
H	B	50 "G" longitudinal accelerometer (U)
I	E	100 "G" longitudinal accelerometer (U)

Notes:

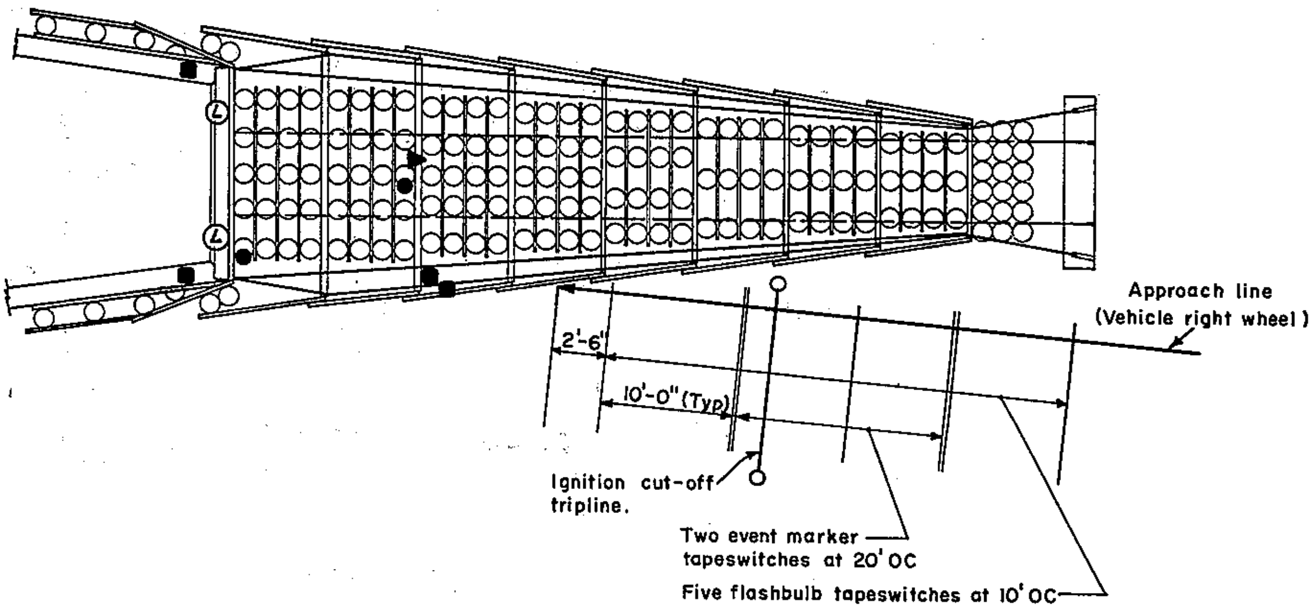
[1] A and E on vehicle floor; C on back of dummy's chest cavity, B in dummy's chest cavity.

[2] (T) = telementry, (U) = umbilical cord.

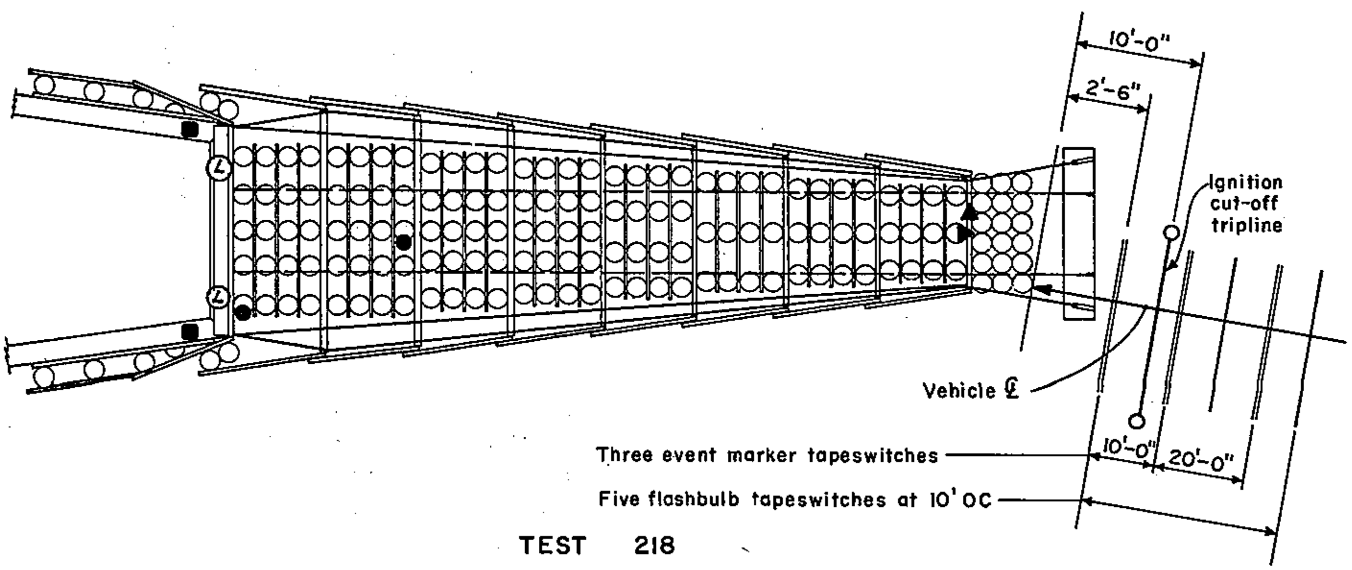
EXHIBIT 12

BARRIER INSTRUMENTATION

TESTS 217 & 218



TEST 217



TEST 218

LEGEND:

- ■ = Strain gage – on top of top and bottom bridgerails and on panels.
- ● = Pressure transducer in water cells.
- Ⓛ = Load cell on main cables
- ▶ = Accelerometer

A P P E N D I X

TABLE NO. 1

Summary - Vehicular Rise

Test No.	Impact Speed (mph)	Avg.Rise-Both Sides-Target on Front Fender over Wheel Well	Avg.Rise-Both Sides-Target on Front Wheel Hubs	Avg.Rise-Both Side-Target on Rear Wheel Hubs
211	14.7	3 in.	None	None
212	33.3	4-1/2" in.	3 in.	None
213	48.2	11 in.	1'-0"	None
214	59.8	-	About 9'-0"*	2'-8-1/2"*
215**	57.5	-	-	-
216	61.8	1'-1/2"	1'-3"	6"
217	57.0	None	None	None
218	59.2	1'-4"	1'-2-1/2"	2"

* Drivers side only
**Car rolled after significant rise

Values in the table represent the average rise from measurements taken on the left and right side of the car. The "±" variation gives an indication of the roll at the time of maximum rise. The degree of extension of the suspension system accounts for the variation in rise between front fender and front wheel hub. In some cases, the target on the front fender was a Scotchlite "butterfly" on the car; in others, the target was a sheet metal square mounted on a target board bolted to the side of the car. In the latter case, it is possible that there are errors of 2-3 in. in the readings due to distortion of the target board during impact; however, no gross distortions of the board were evident in the movies. Errors in the readings are probably on the order of 1-2 in.; these errors are due to the lack of a well defined reference plane in the movies and other inaccuracies inherent in the use of data film for this type of measurement.

TABLE NO. 2

Maximum Loads on Cables

Test No.	Impact Conditions	Max. Load (lbs)	Preload (lbs)
216	61.8 mph, headon, nose		
Left		14,750	3,000
Right		18,750	3,000
217	57.0 mph, angle, side		
Left		14,300	2,500
Right		11,500	2,500
218	59.2 mph, angle, nose		
Left		20,900	None recorded
Right		5,450	" "

A time history of loads during impact was recorded for the two main 7/8 inch diameter cables using compressive load cells bearing against the backup plate. The values above were the maximum loads recorded. Breaking strength of the cables was assumed to be about 62 kips each; therefore, the 7/8 inch cable appears to be adequate.

TABLE NO. 3

Maximum Stress in Bridge Approach Guardrail

Test No.	Location	Impact Speed (mph)	Impact Location	Max. Stress (psi)
215		57.5	Headon, Nose	
	Top left			4,500
	Bottom left			2,940
	Top right			3,420
	Bottom right			3,100
216		61.8	Headon, Nose	
	Top left			12,200
	Bottom left			3,060
	Top right			15,500
	Bottom right			6,300
217		57.0	Angle, Side	
	Top left			6,240
	Bottom left			9,850
	Top right			3,540
	Bottom right			5,400
218		59.2	Angle, Nose	
	Top left			5,360
	Bottom left			4,800
	Top right			12,000
	Bottom right			5,850

These values were determined using the maximum strain indicated by the gages designated on Exhibits 10 and 12 of this report. An assumed Youngs modulus of 30 ksi was used for the calculation of maximum stress (compression).

TABLE NO. 4

Maximum Lap Belt Load

Test No.	Impact Velocity (mph)	Load (lbs)
215	57.5	513
216	61.8	533
217	-	Not measured
218	-	Not measured

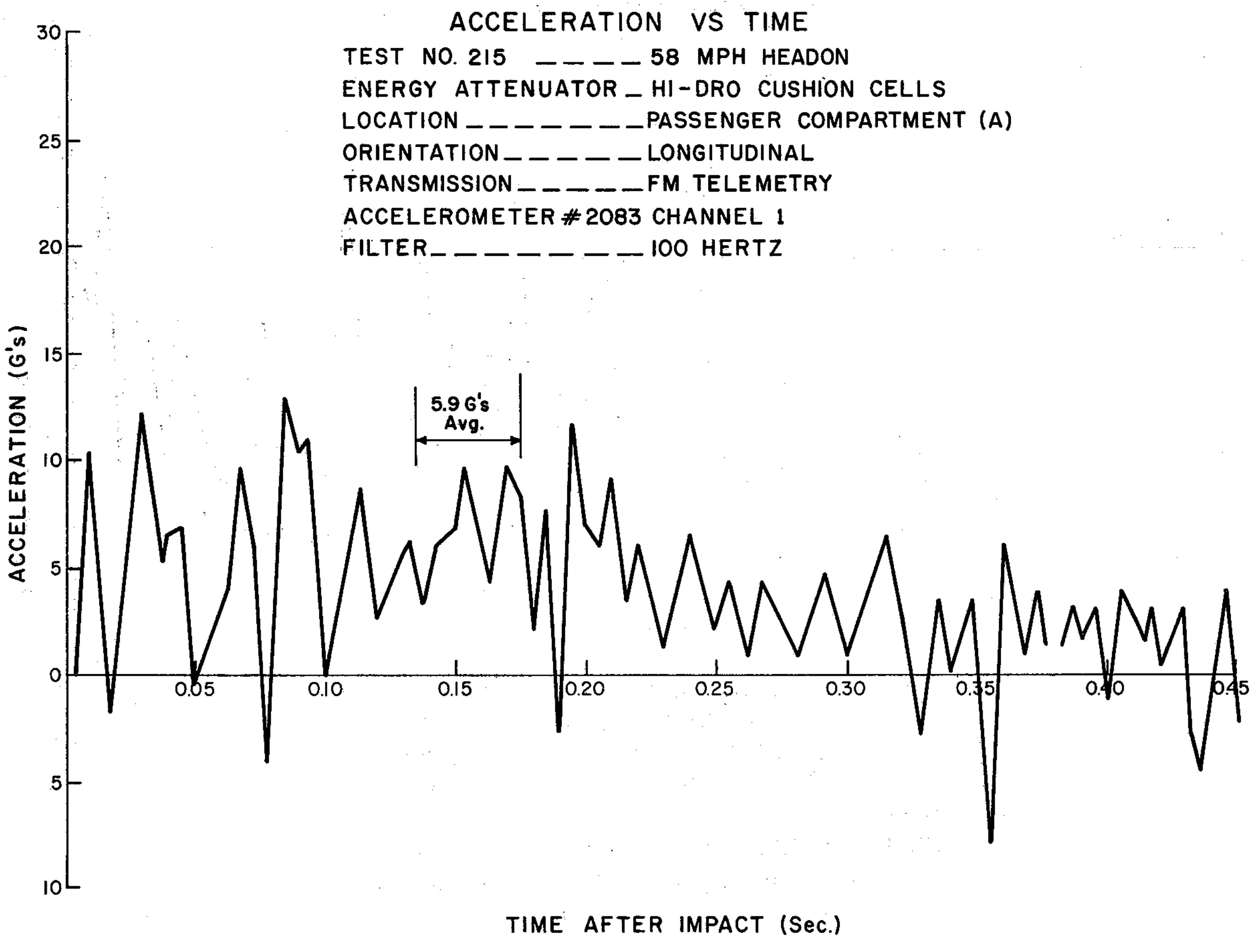
In the above tests, Stan, the 165 lb. dummy, was restrained with a lap belt only. The values represent the load on one side of the lap belt loop, so the total load applied to the dummy was approximately twice the above values. Federal Standards[8] require lap belts to resist a total load of 5,000 lbs., which is considered tolerable for an average driver provided the lap belt is maintained around the pelvis bones and does not slide up into the more vulnerable abdominal area. On this basis, the measured loads above do not appear to be dangerous.

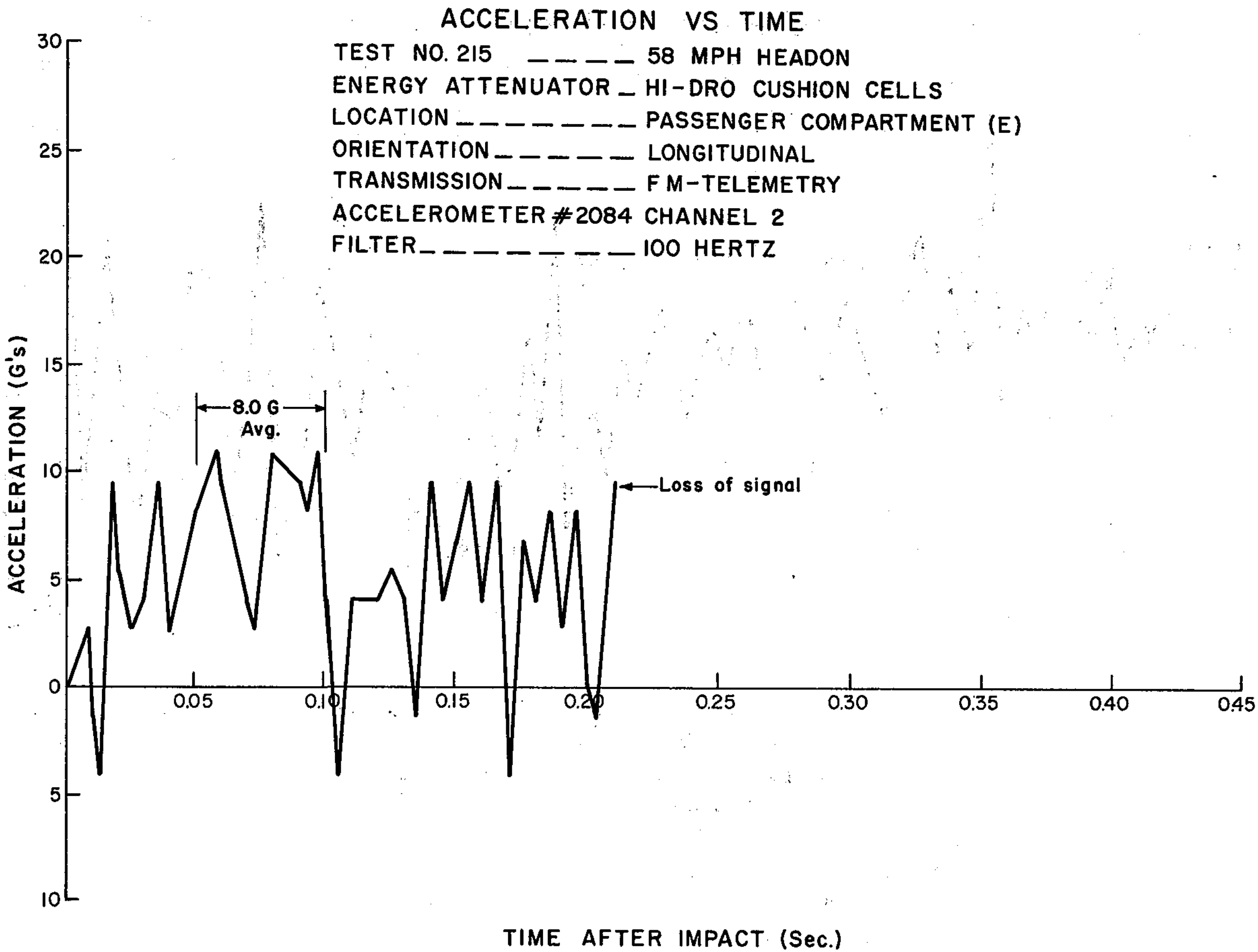
TABLE NO. 5

Maximum Load on Dummy's Chest

Test No.	Impact Velocity (mph)	Load (lbs)	Steering Column Collapse (in.)
215	57.5 Headon, Nose	470	0
216	61.8 Headon, Nose	530	2.9
217	57.0 Angle, Side	Not Measured	0
218	59.2 Angle, Nose	175	0

The time history of chest deflection was the actual recorded measurement. The maximum deflection was determined, and a corresponding load was found on a force versus displacement chart for the dummy. Federal standards[8] limit the impact force of a simulated body traveling at a relative velocity of 15 mph to 2,500 lbs. when impacting the steering control system. The collapsible steering column designed for 1967 model cars by General Motors was intended to limit the chest load at impact to 1,000-1,500 lbs. A static load test on one of the collapsible steering columns from a 1968 Dodge sedan resulted in an initial collapse load of about 1,500 lbs. and a fluctuating load thereafter of 500 to 750 lbs. It appears, then, that our measured chest loads may have been lower than the actual loads, however, it is still probable that the actual loads were well within tolerable human limits such that there would be no serious injuries or fatalities sustained. The steering wheels in all the above tests were deformed in varying amounts in addition to the steering column collapse. The maximum possible steering column collapse in the 1968 Dodges is 4.2 inches.


ACCELERATION VS TIME
TEST NO. 215 ————58 MPH HEADON
ENERGY ATTENUATOR — HI-DRO CUSHION CELLS
LOCATION ————————PASSENGER COMPARTMENT (A)
ORIENTATION——————LONGITUDINAL
TRANSMISSION——————FM TELEMETRY
ACCELEROMETER #2083 CHANNEL 1
FILTER——————————100 HERTZ
5.9 G's Avg.
ACCELERATION (G's)
30
25
20
15
10
5
0
5
10
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
TIME AFTER IMPACT (Sec.)


ACCELERATION VS TIME
TEST NO. 215 ———— 58 MPH HEADON
ENERGY ATTENUATOR — HI-DRO CUSHION CELLS
LOCATION ———————— PASSENGER COMPARTMENT (E)
ORIENTATION —————— LONGITUDINAL
TRANSMISSION —————— FM-TELEMETRY
ACCELEROMETER #2084 CHANNEL 2
FILTER ———————— 100 HERTZ
8.0 G Avg.
Loss of signal
ACCELERATION (G's)
30
25
20
15
10
5
0
5
10
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
TIME AFTER IMPACT (Sec.)

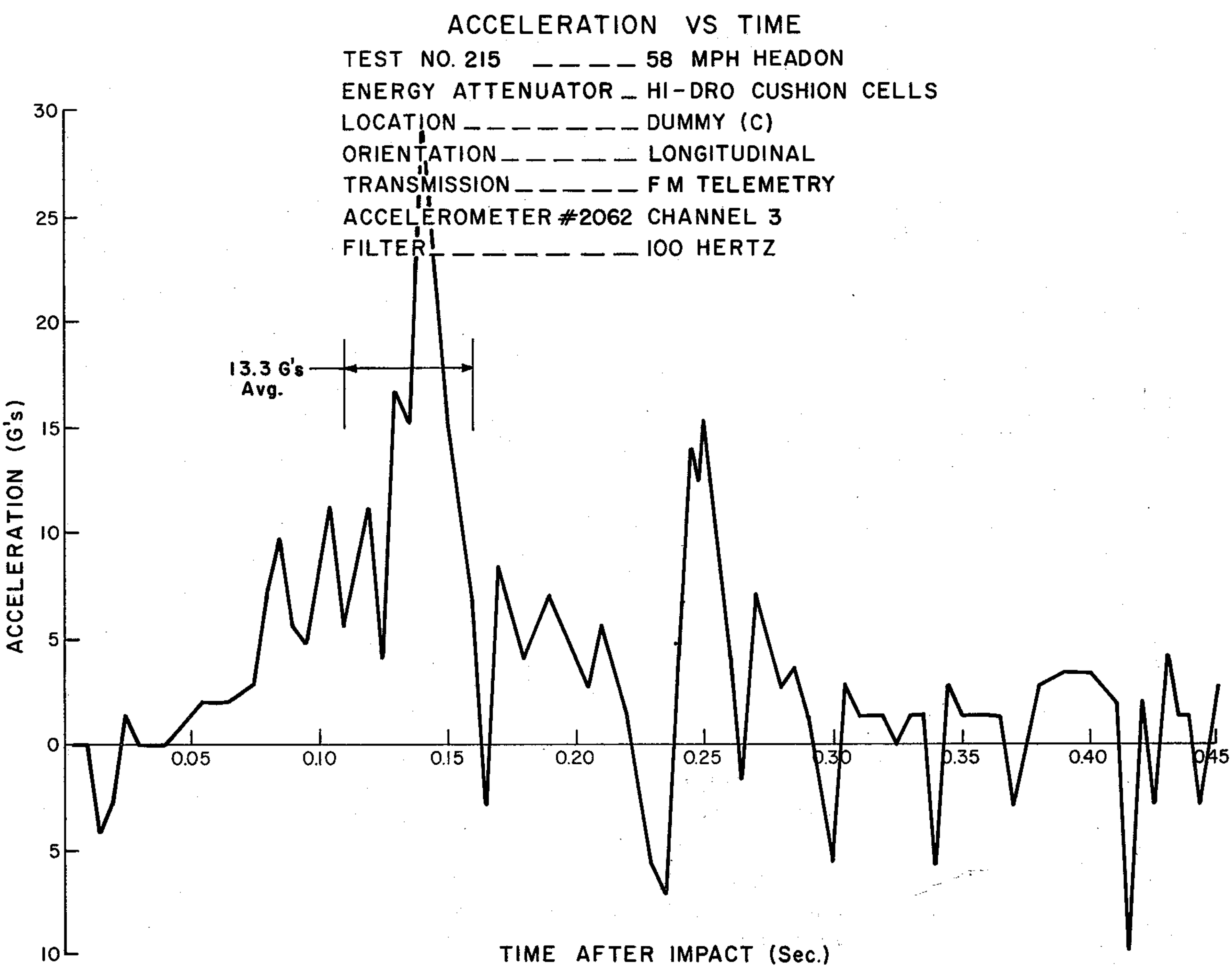
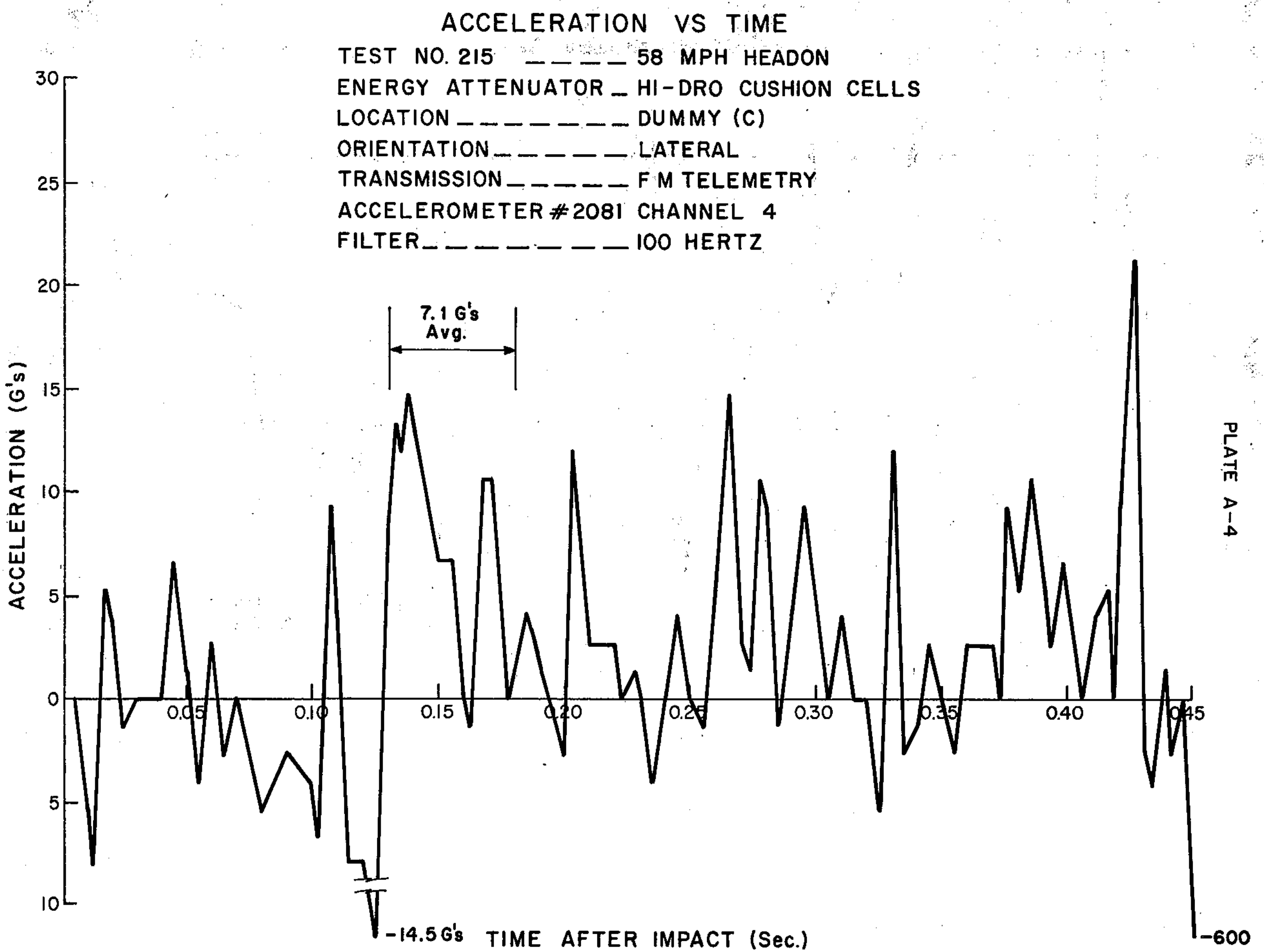

ACCELERATION VS TIME
TEST NO. 215 — — — — 58 MPH HEADON
ENERGY ATTENUATOR — HI-DRO CUSHION CELLS
LOCATION — — — — — — — — DUMMY (C)
ORIENTATION — — — — — — LONGITUDINAL
TRANSMISSION — — — — — — F M TELEMETRY
ACCELEROMETER #2062 CHANNEL 3
FILTER — — — — — — — — 100 HERTZ
13.3 G's Avg.
ACCELERATION (G's)
30
25
20
15
10
5
0
5
10
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
TIME AFTER IMPACT (Sec.)

PLATE A-4


ACCELERATION VS TIME
TEST NO. 215 — — — — 58 MPH HEADON
ENERGY ATTENUATOR — HI-DRO CUSHION CELLS
LOCATION — — — — — — — — DUMMY (C)
ORIENTATION — — — — — — LATERAL
TRANSMISSION — — — — — — F M TELEMETRY
ACCELEROMETER #2081 CHANNEL 4
FILTER — — — — — — — — 100 HERTZ
7.1 G's Avg.
-14.5 G's
-600
ACCELERATION (G's)
TIME AFTER IMPACT (Sec.)
30
25
20
15
10
5
0
5
10
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45

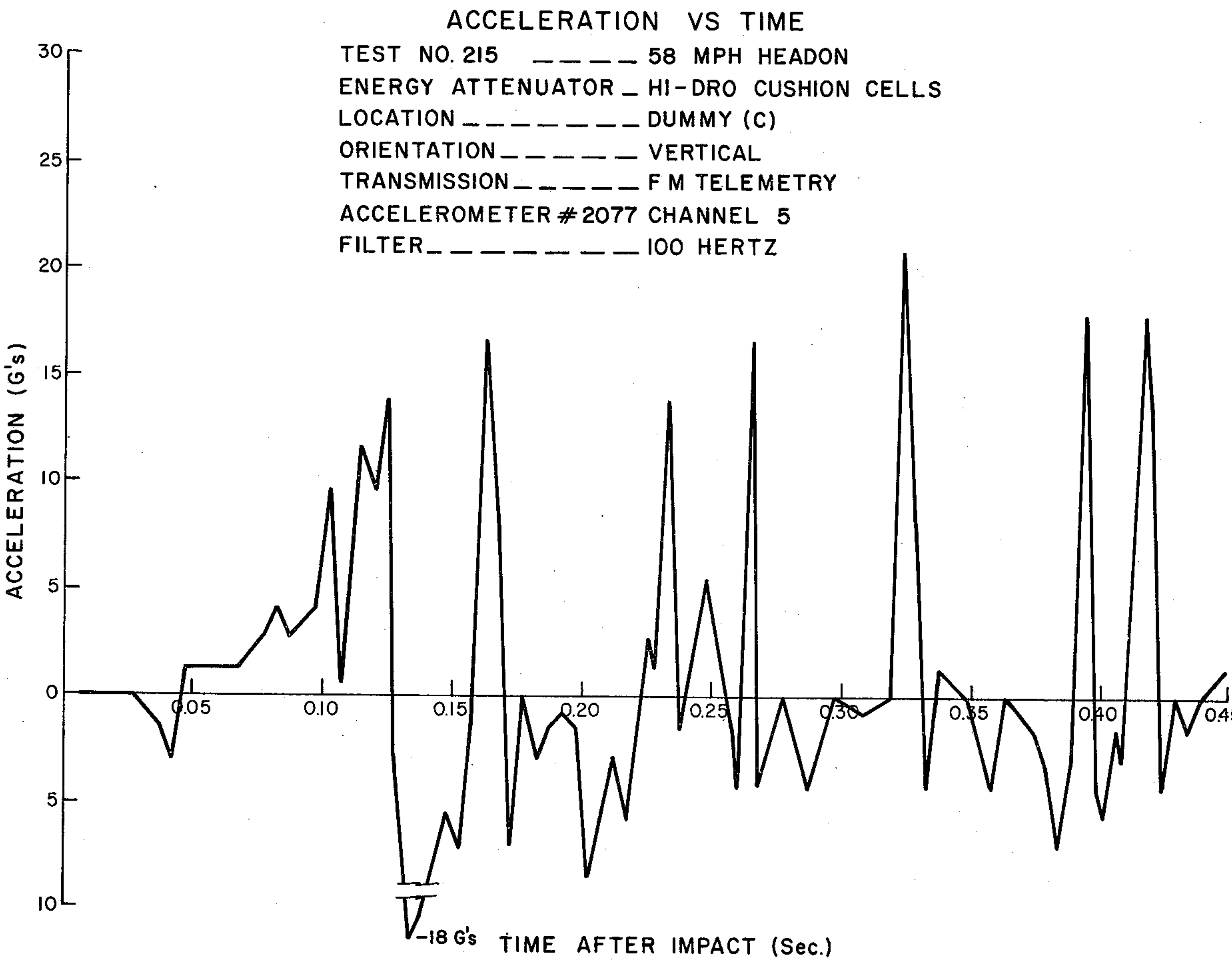
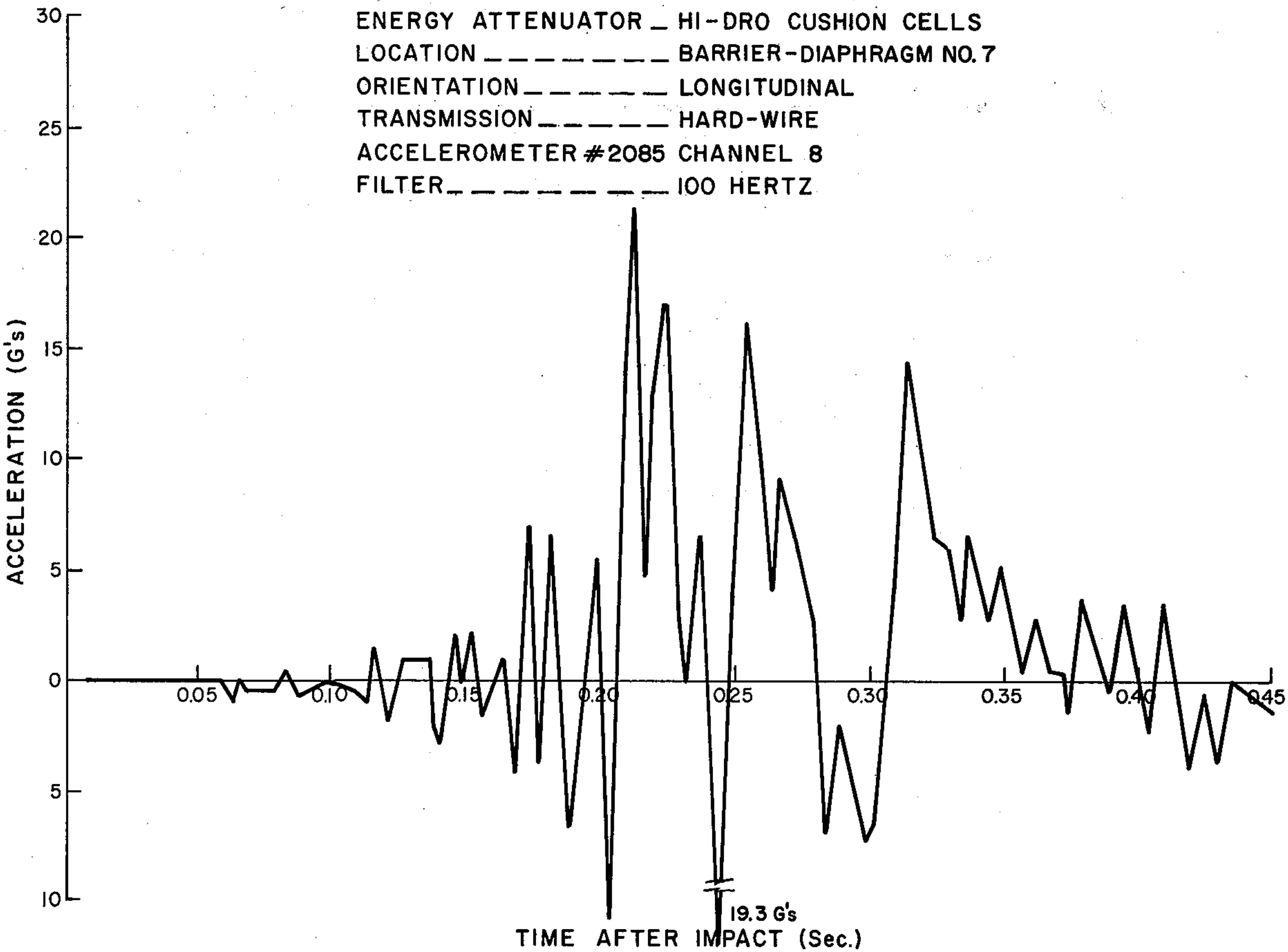

ACCELERATION VS TIME
TEST NO. 215 ———— 58 MPH HEADON
ENERGY ATTENUATOR — HI-DRO CUSHION CELLS
LOCATION ———————— DUMMY (C)
ORIENTATION —————— VERTICAL
TRANSMISSION —————— F M TELEMETRY
ACCELEROMETER # 2077 CHANNEL 5
FILTER ———————— 100 HERTZ
ACCELERATION (G's)
30
25
20
15
10
5
0
5
10
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
-18 G's
TIME AFTER IMPACT (Sec.)

PLATE A-6

ACCELERATION VS TIME

TEST NO. 215 ———— 58 MPH HEADON
ENERGY ATTENUATOR — HI-DRO CUSHION CELLS
LOCATION ———————— BARRIER-DIAPHRAGM NO. 7
ORIENTATION —————— LONGITUDINAL
TRANSMISSION —————— HARD-WIRE
ACCELEROMETER #2085 CHANNEL 8
FILTER ———————— 100 HERTZ



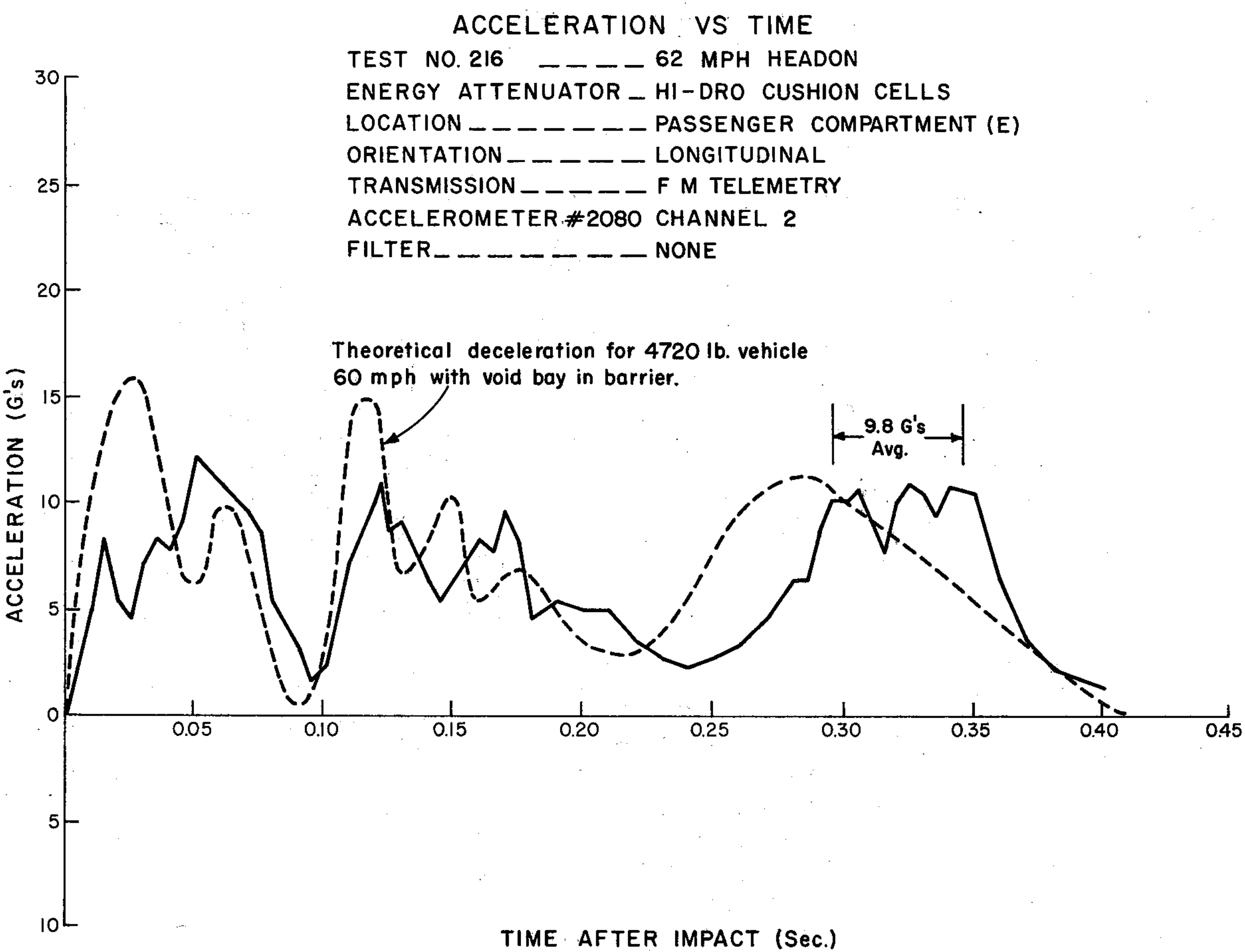
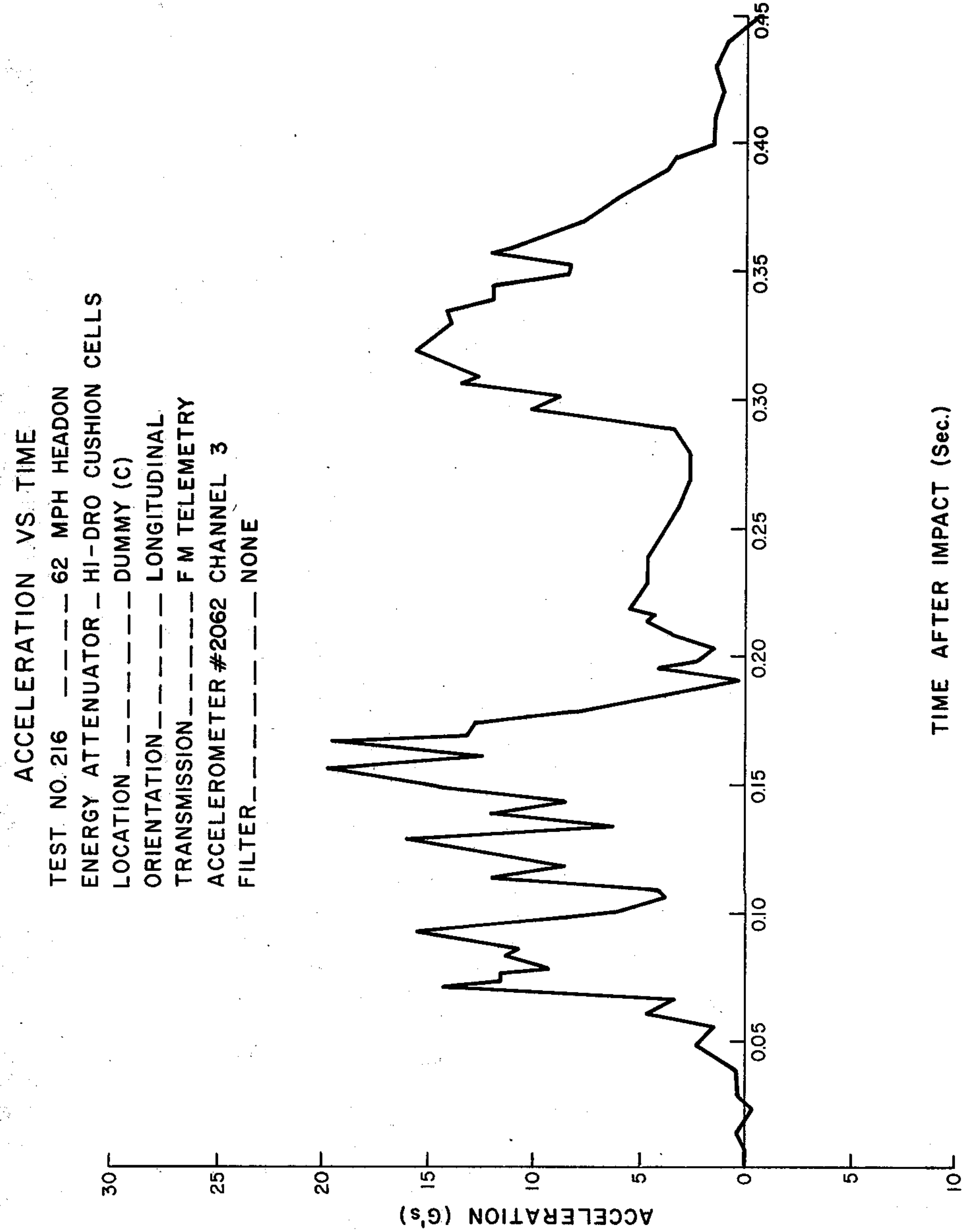
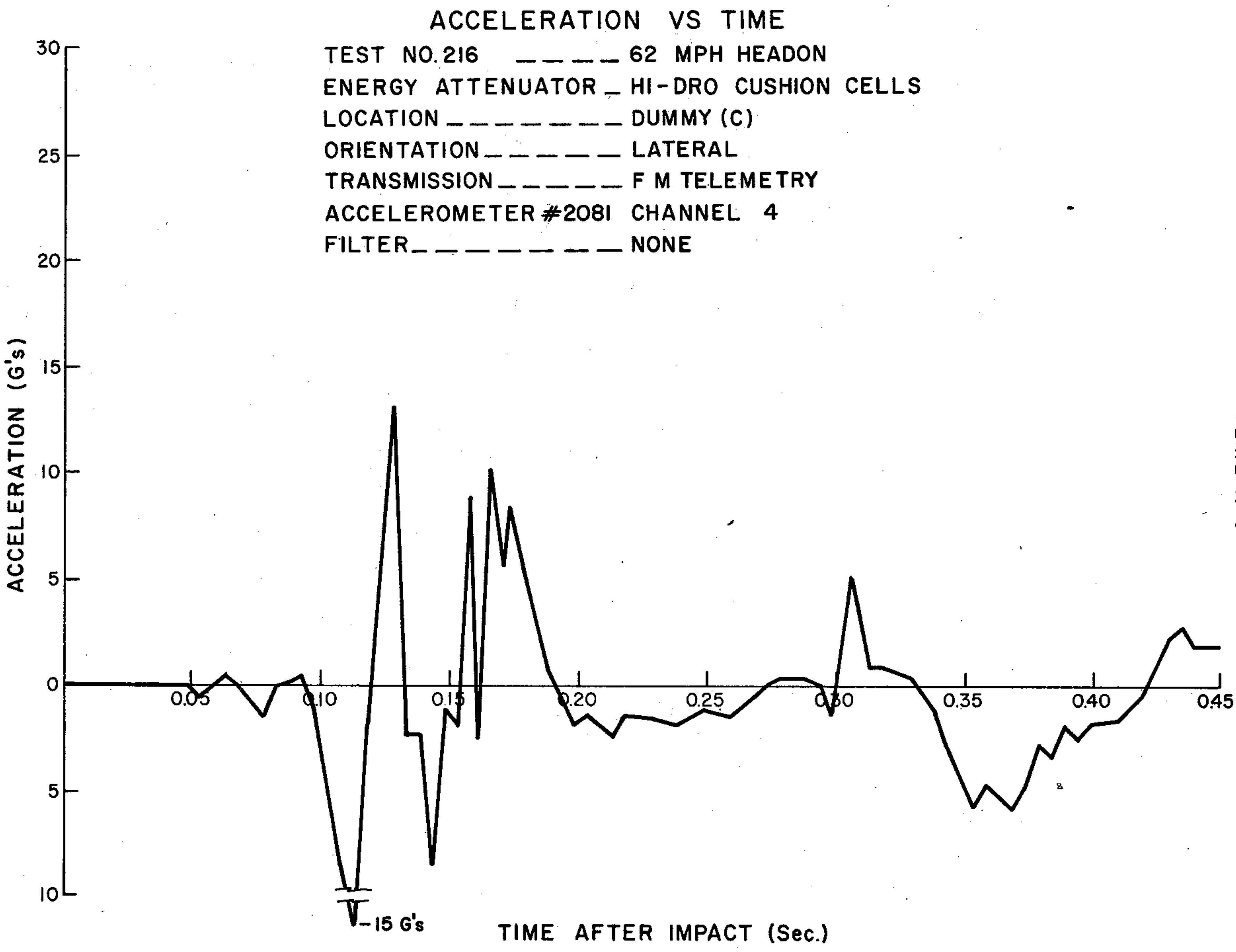
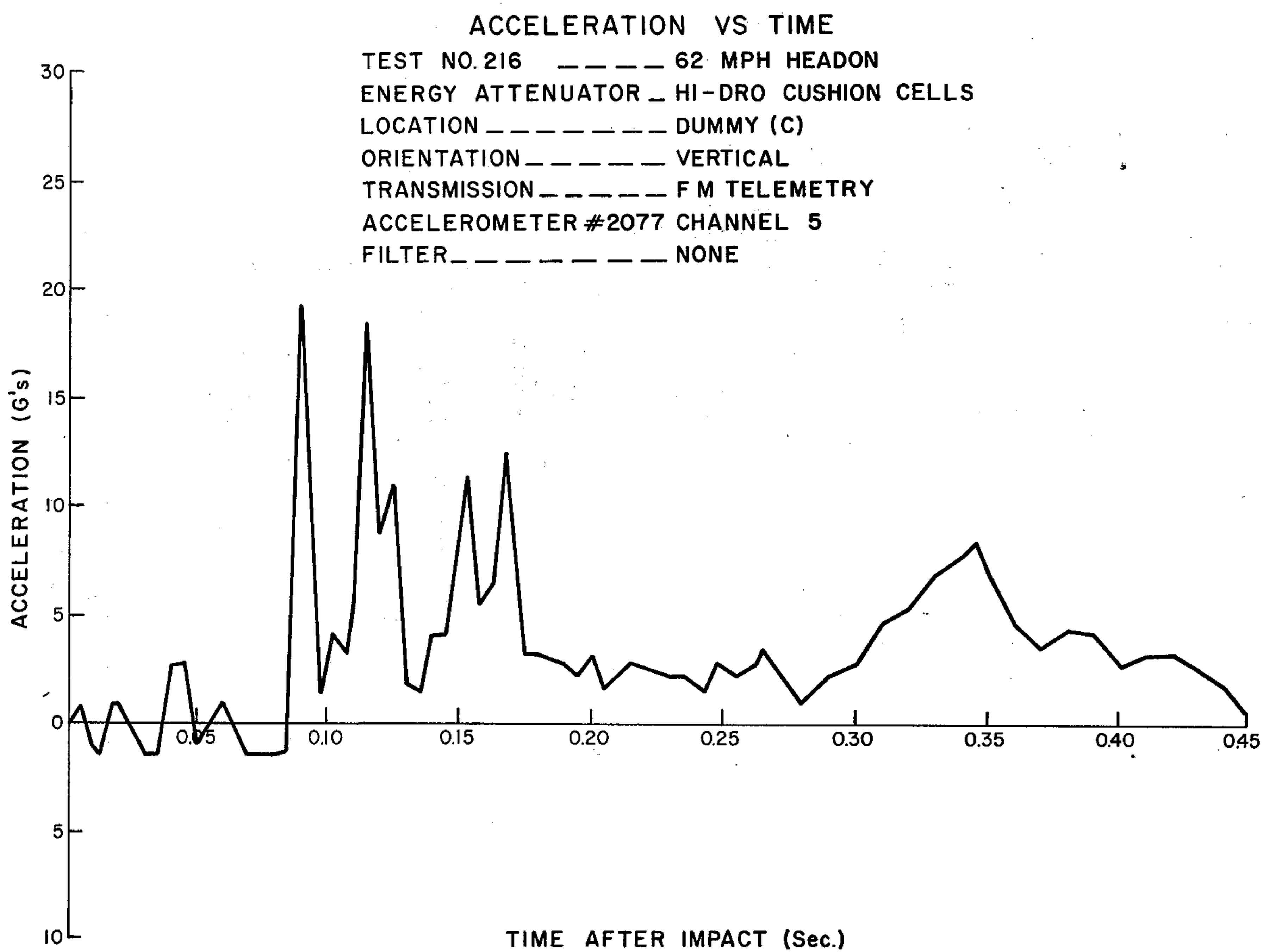

ACCELERATION VS TIME
TEST NO. 216 ———— 62 MPH HEADON
ENERGY ATTENUATOR — HI-DRO CUSHION CELLS
LOCATION ———————— PASSENGER COMPARTMENT (E)
ORIENTATION —————— LONGITUDINAL
TRANSMISSION ————— F M TELEMETRY
ACCELEROMETER #2080 CHANNEL 2
FILTER ————————— NONE
Theoretical deceleration for 4720 lb. vehicle 60 mph with void bay in barrier.
9.8 G's Avg.
ACCELERATION (G's)
30
25
20
15
10
5
0
5
10
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
TIME AFTER IMPACT (Sec.)

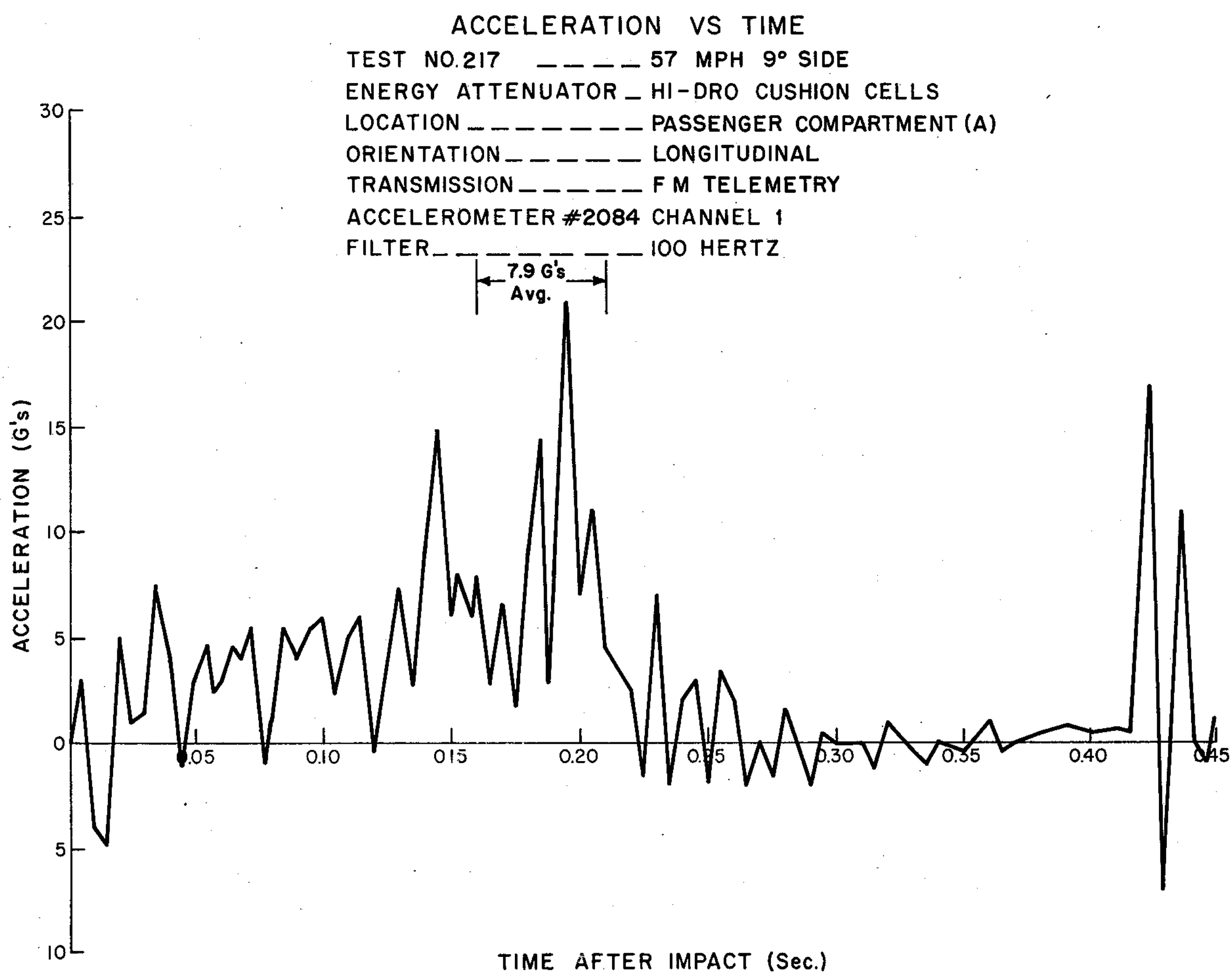
PLATE A-8



ACCELERATION VS TIME
TEST NO. 216 — — — — 62 MPH HEADON
ENERGY ATTENUATOR _ HI-DRO CUSHION CELLS
LOCATION — — — — — DUMMY (C)
ORIENTATION — — — — LONGITUDINAL
TRANSMISSION — — — F M TELEMETRY
ACCELEROMETER #2062 CHANNEL 3
FILTER — — — — — NONE
ACCELERATION (G's)
30
25
20
15
10
5
0
5
10
TIME AFTER IMPACT (Sec.)
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45


ACCELERATION VS TIME
TEST NO. 216 _ _ _ _ 62 MPH HEADON
ENERGY ATTENUATOR _ HI-DRO CUSHION CELLS
LOCATION _ _ _ _ _ _ _ _ DUMMY (C)
ORIENTATION _ _ _ _ _ _ LATERAL
TRANSMISSION _ _ _ _ _ _ F M TELEMETRY
ACCELEROMETER #2081 CHANNEL 4
FILTER _ _ _ _ _ _ _ _ _ NONE
ACCELERATION (G's)
30
25
20
15
10
5
0
5
10
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
-15 G's
TIME AFTER IMPACT (Sec.)


ACCELERATION VS TIME
TEST NO. 216 _ _ _ _ _ 62 MPH HEADON
ENERGY ATTENUATOR _ HI-DRO CUSHION CELLS
LOCATION _ _ _ _ _ _ _ _ _ DUMMY (C)
ORIENTATION _ _ _ _ _ _ VERTICAL
TRANSMISSION _ _ _ _ _ _ F M TELEMETRY
ACCELEROMETER #2077 CHANNEL 5
FILTER _ _ _ _ _ _ _ _ _ _ NONE
ACCELERATION (G's)
30
25
20
15
10
5
0
5
10
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
TIME AFTER IMPACT (Sec.)


ACCELERATION VS TIME
TEST NO. 217 ____ 57 MPH 9° SIDE
ENERGY ATTENUATOR _ HI-DRO CUSHION CELLS
LOCATION ________ PASSENGER COMPARTMENT (A)
ORIENTATION ______ LONGITUDINAL
TRANSMISSION ______ F M TELEMETRY
ACCELEROMETER #2084 CHANNEL 1
FILTER __________ 100 HERTZ
7.9 G's Avg.
30
25
20
15
10
5
0
5
10
ACCELERATION (G's)
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
TIME AFTER IMPACT (Sec.)

ACCELERATION VS TIME

TEST NO. 217 ———— 57 MPH 9° SIDE
ENERGY ATTENUATOR — HI-DRO CUSHION CELLS
LOCATION ———————— PASSENGER COMPARTMENT (E)
ORIENTATION —————— LONGITUDINAL
TRANSMISSION —————— F M TELEMETRY
ACCELEROMETER #2085 CHANNEL 3
FILTER ———————— 100 HERTZ

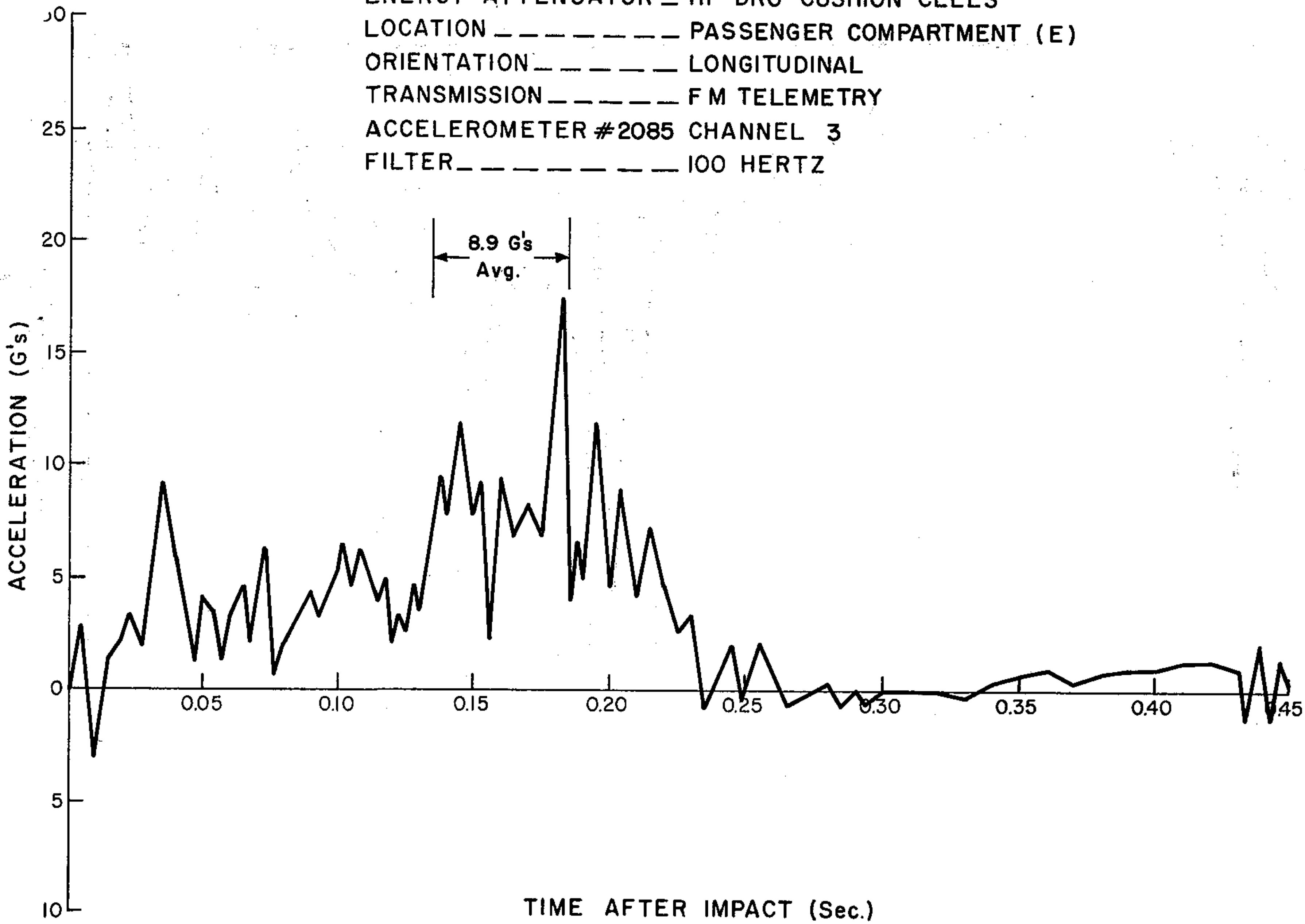
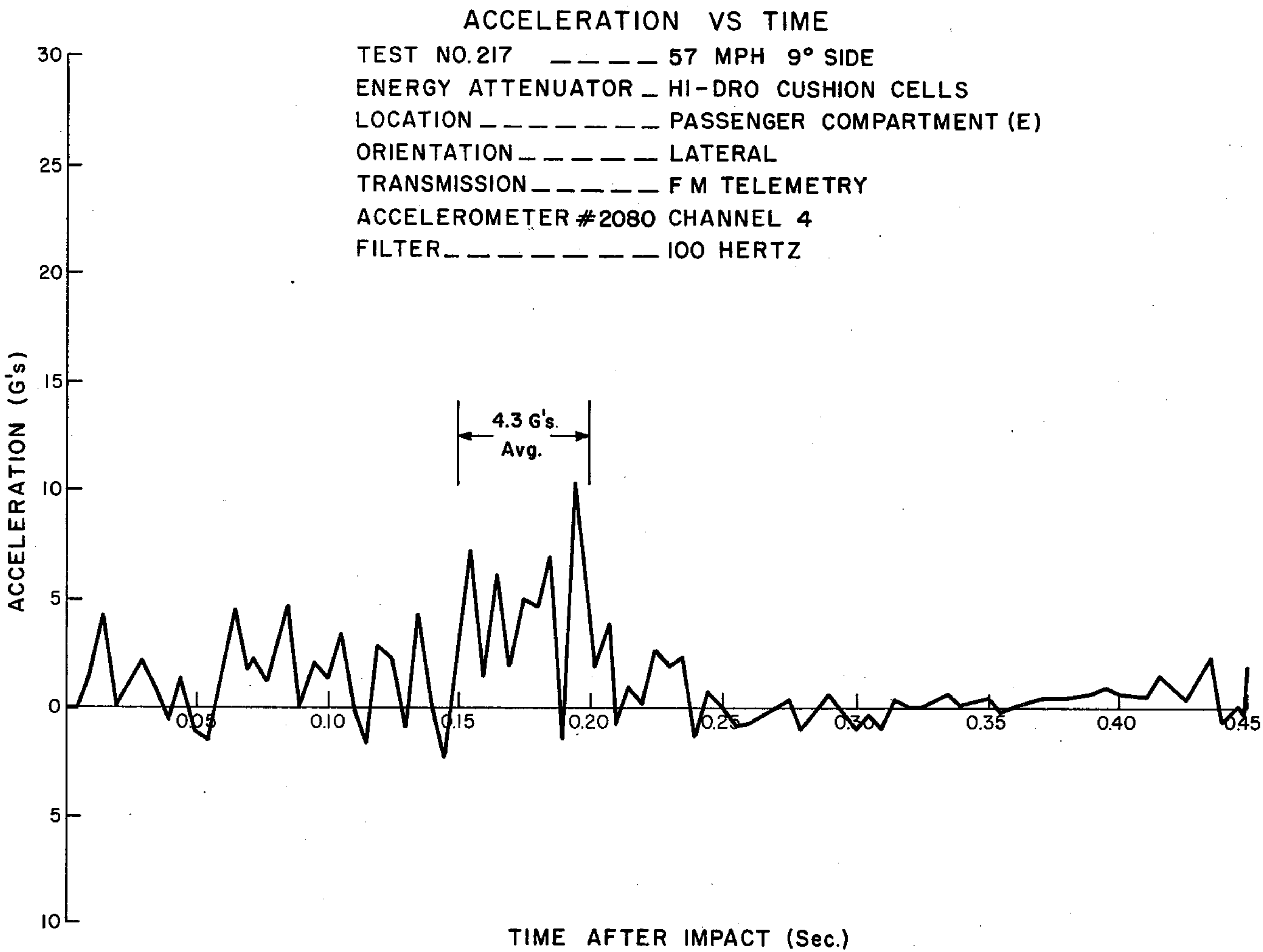
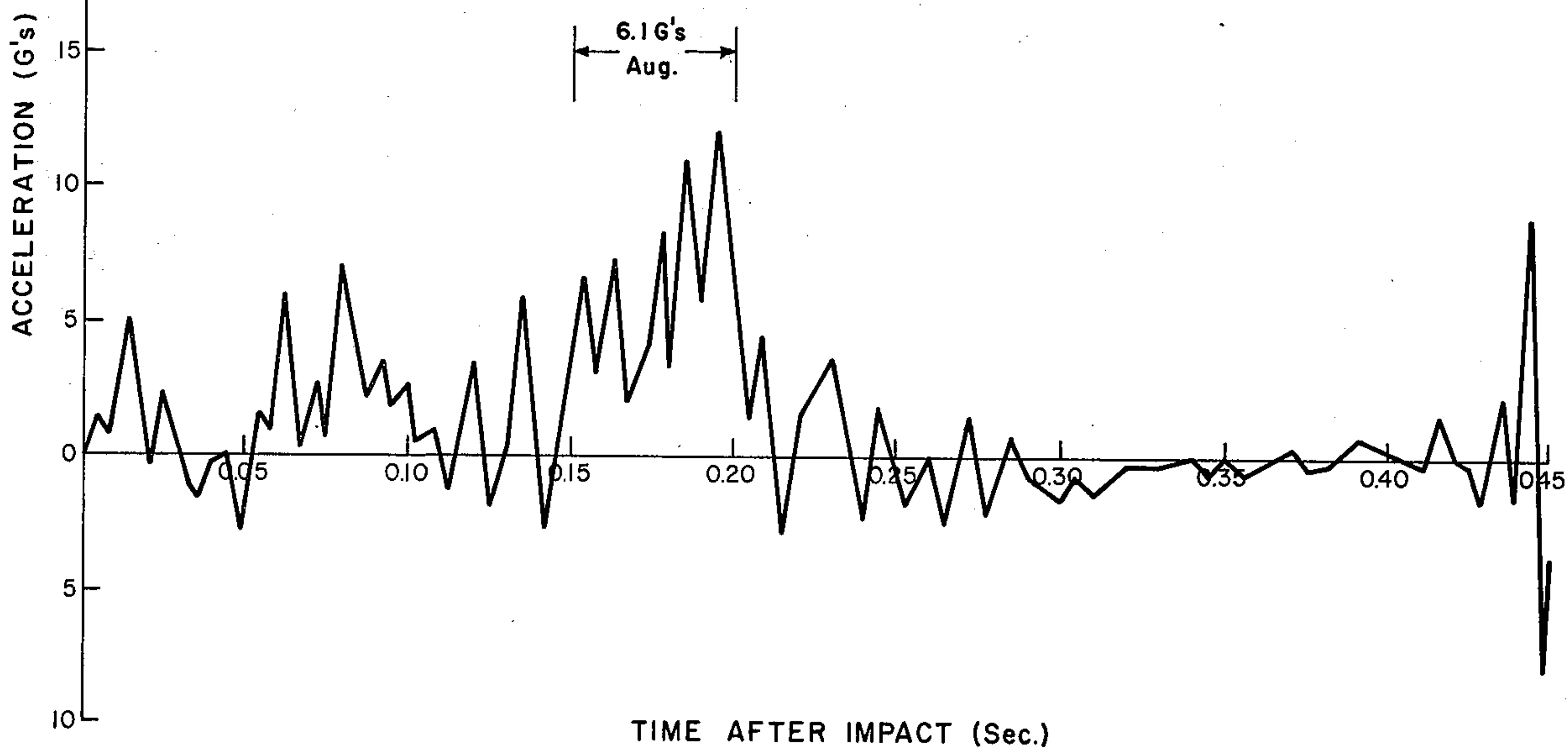


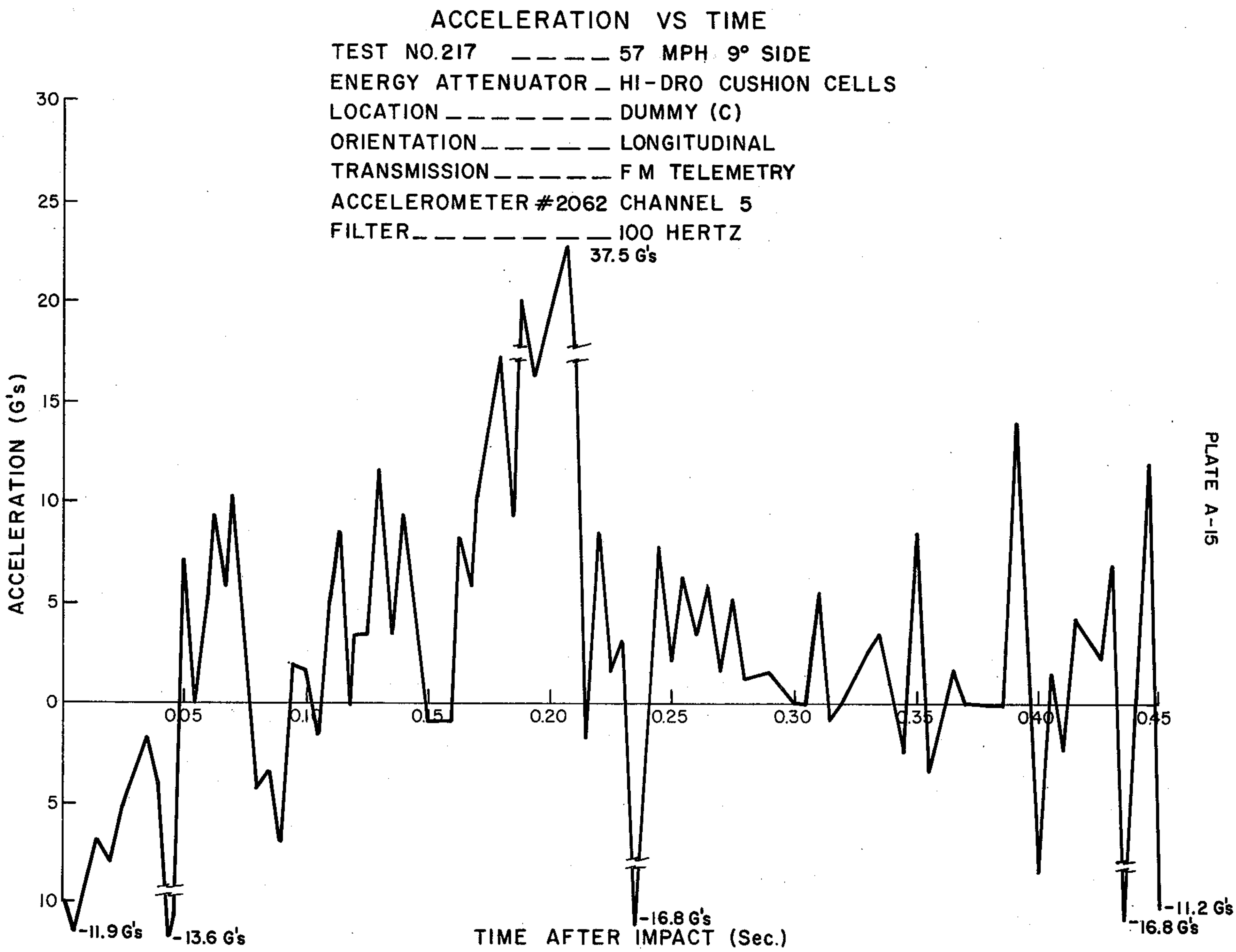
PLATE A-13

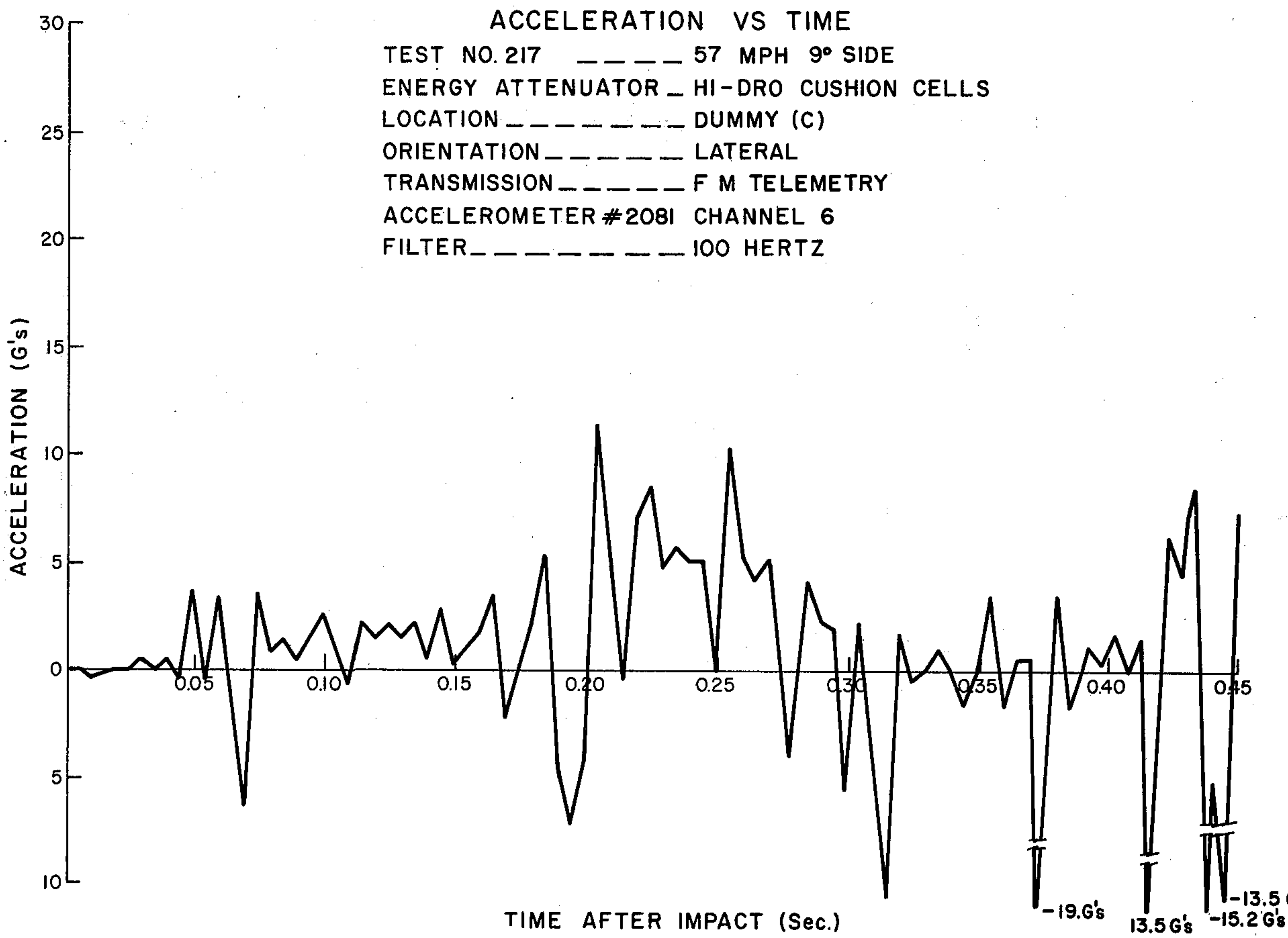

ACCELERATION VS TIME
TEST NO. 217 ———— 57 MPH 9° SIDE
ENERGY ATTENUATOR — HI-DRO CUSHION CELLS
LOCATION ———————— PASSENGER COMPARTMENT (E)
ORIENTATION —————— LATERAL
TRANSMISSION —————— F M TELEMETRY
ACCELEROMETER #2080 CHANNEL 4
FILTER ————————— 100 HERTZ
4.3 G's. Avg.
ACCELERATION (G's)
30
25
20
15
10
5
0
5
10
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
TIME AFTER IMPACT (Sec.)

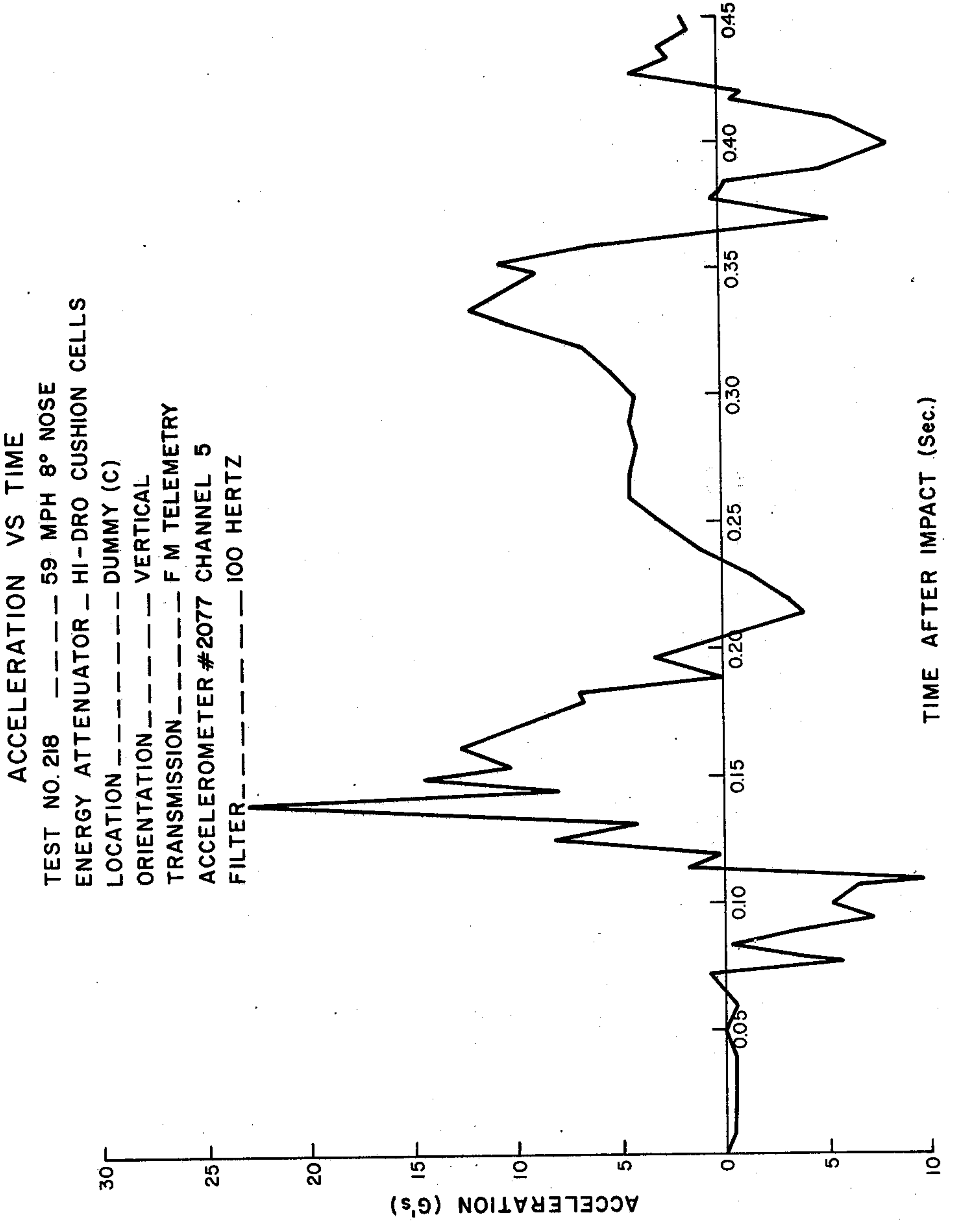
ACCELERATION VS TIME

TEST NO. 217 ————	57 MPH 9° SIDE
ENERGY ATTENUATOR —	HI-DRO CUSHION CELLS
LOCATION ————————	PASSENGER COMPARTMENT (A)
ORIENTATION ——————	LATERAL
TRANSMISSION ——————	F M TELEMETRY
ACCELEROMETER #2083	CHANNEL 2
FILTER ————————	100 HERTZ




ACCELERATION VS TIME
TEST NO.217 _ _ _ _ 57 MPH 9° SIDE
ENERGY ATTENUATOR _ HI-DRO CUSHION CELLS
LOCATION _ _ _ _ _ _ _ _ DUMMY (C)
ORIENTATION _ _ _ _ _ _ LONGITUDINAL
TRANSMISSION _ _ _ _ _ F M TELEMETRY
ACCELEROMETER #2062 CHANNEL 5
FILTER _ _ _ _ _ _ _ _ _ 100 HERTZ
37.5 G's
-11.9 G's
-13.6 G's
-16.8 G's
-16.8 G's
-11.2 G's
ACCELERATION (G's)
30
25
20
15
10
5
0
5
10
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
TIME AFTER IMPACT (Sec.)


ACCELERATION VS TIME
TEST NO. 217 ____ 57 MPH 9° SIDE
ENERGY ATTENUATOR _ HI-DRO CUSHION CELLS
LOCATION ________ DUMMY (C)
ORIENTATION ______ LATERAL
TRANSMISSION ______ F M TELEMETRY
ACCELEROMETER #2081 CHANNEL 6
FILTER ________ 100 HERTZ
ACCELERATION (G's)
30
25
20
15
10
5
0
5
10
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
-19.G's
13.5 G's
-15.2 G's
-13.5 G's
TIME AFTER IMPACT (Sec.)


ACCELERATION VS TIME
TEST NO. 218 ———— 59 MPH 8° NOSE
ENERGY ATTENUATOR _ HI-DRO CUSHION CELLS
LOCATION ———— DUMMY (C)
ORIENTATION ———— VERTICAL
TRANSMISSION ———— F M TELEMETRY
ACCELEROMETER #2077 CHANNEL 5
FILTER ———— 100 HERTZ
ACCELERATION (G's)
30
25
20
15
10
5
0
5
10
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
TIME AFTER IMPACT (Sec.)

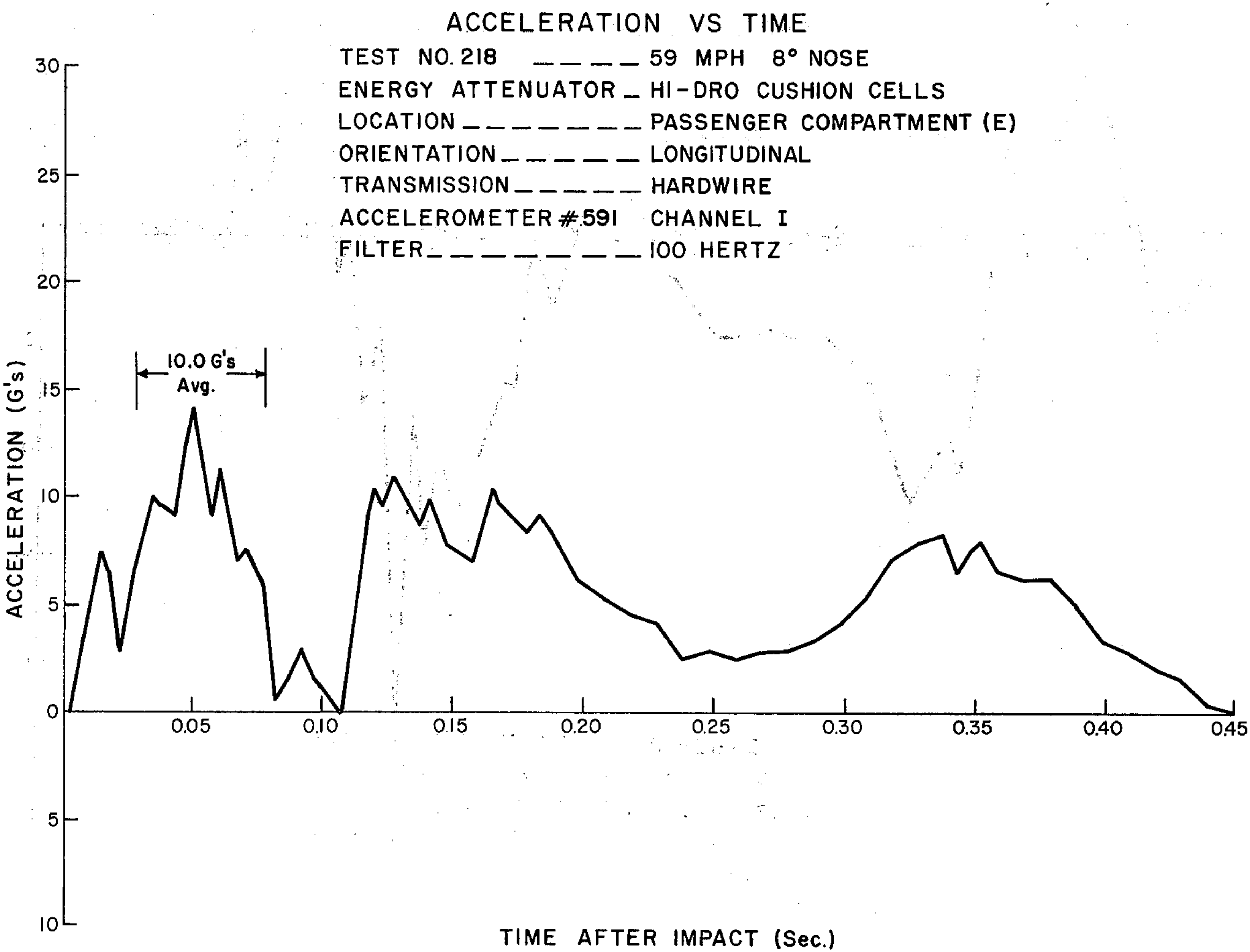
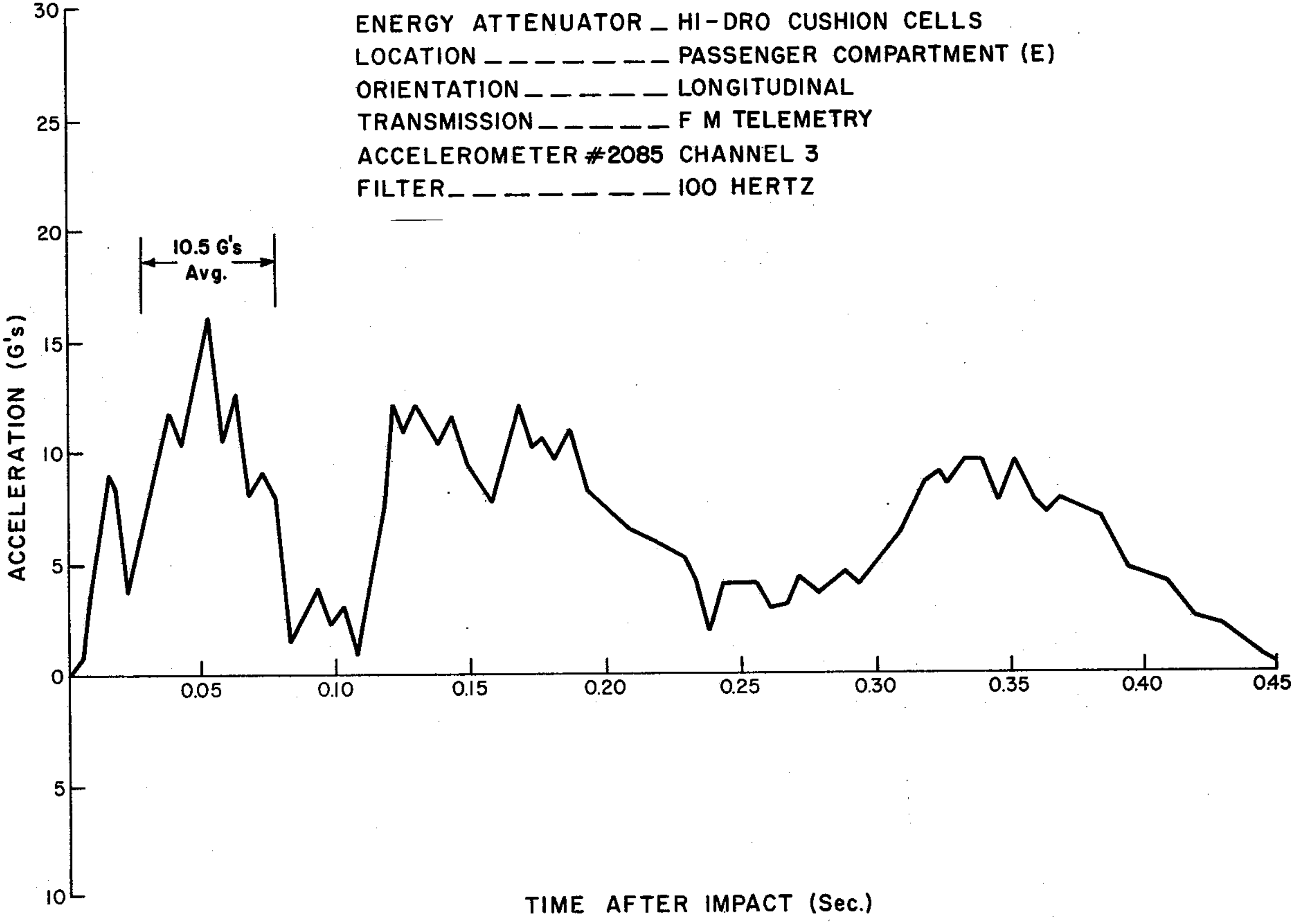
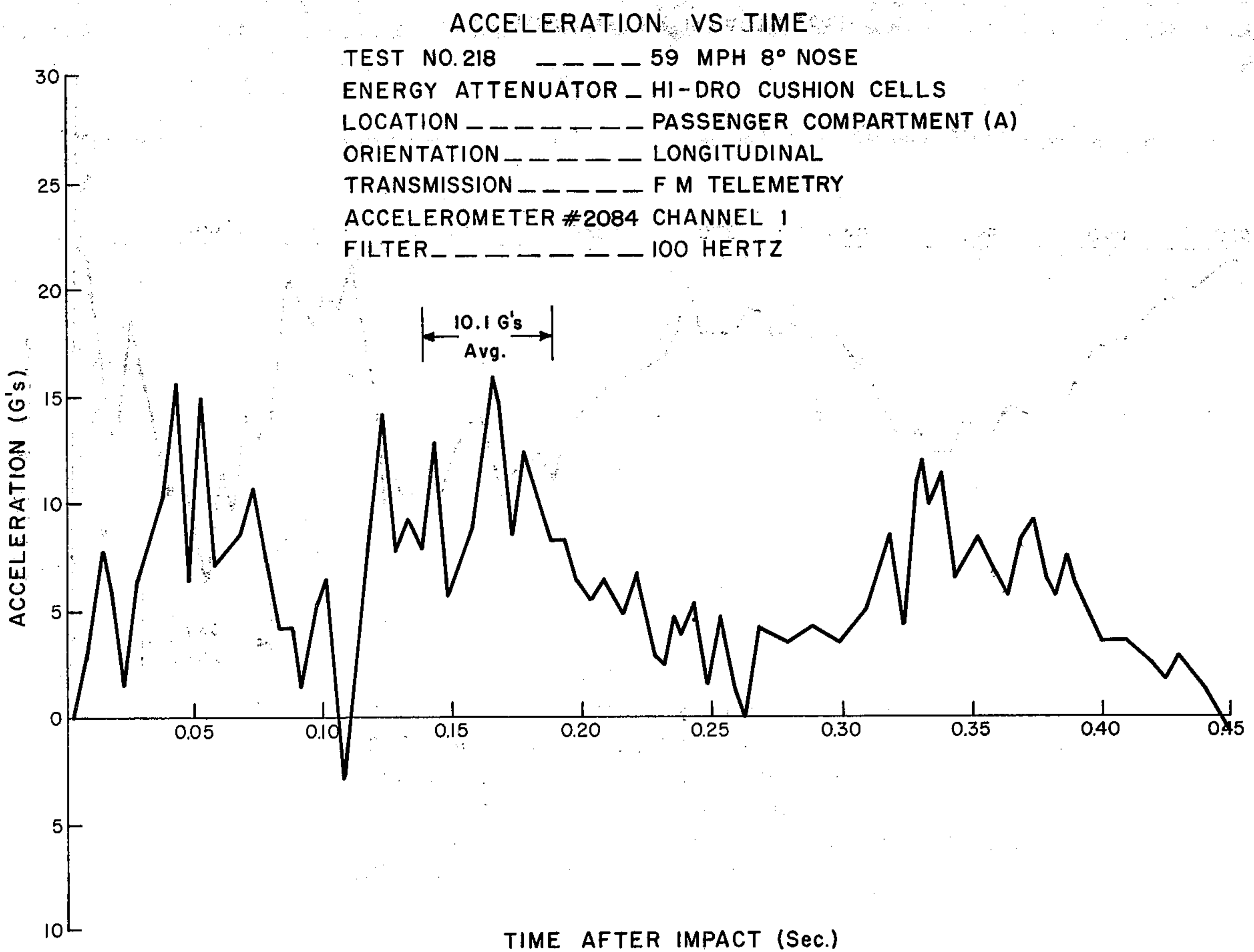

ACCELERATION VS TIME
TEST NO. 218 _ _ _ _ 59 MPH 8° NOSE
ENERGY ATTENUATOR _ HI-DRO CUSHION CELLS
LOCATION _ _ _ _ _ _ _ _ PASSENGER COMPARTMENT (E)
ORIENTATION _ _ _ _ _ _ LONGITUDINAL
TRANSMISSION _ _ _ _ _ _ HARDWIRE
ACCELEROMETER #591 CHANNEL I
FILTER _ _ _ _ _ _ _ _ _ 100 HERTZ
10.0 G's Avg.
ACCELERATION (G's)
30
25
20
15
10
5
0
5
10
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
TIME AFTER IMPACT (Sec.)

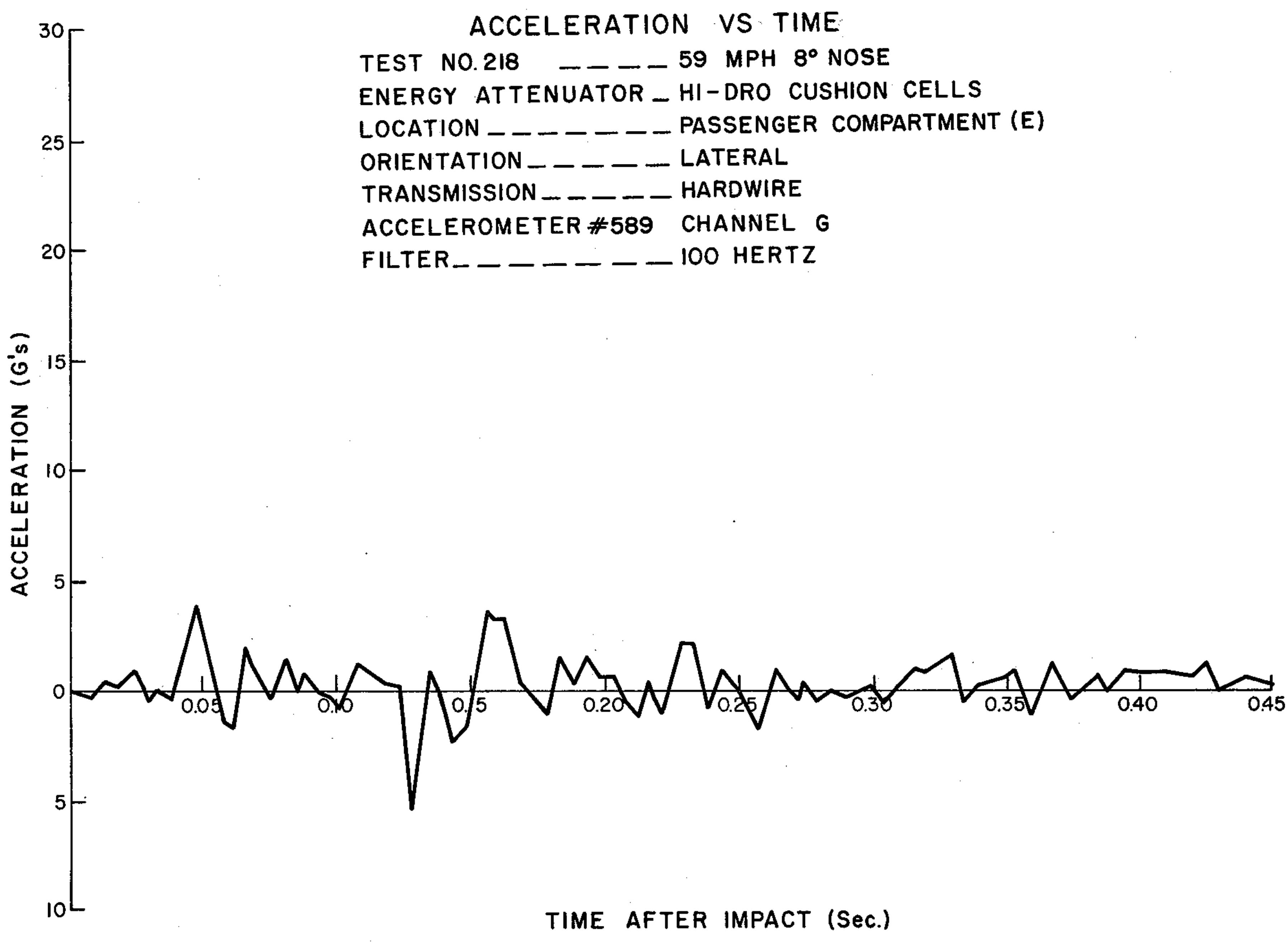
PLATE A-19

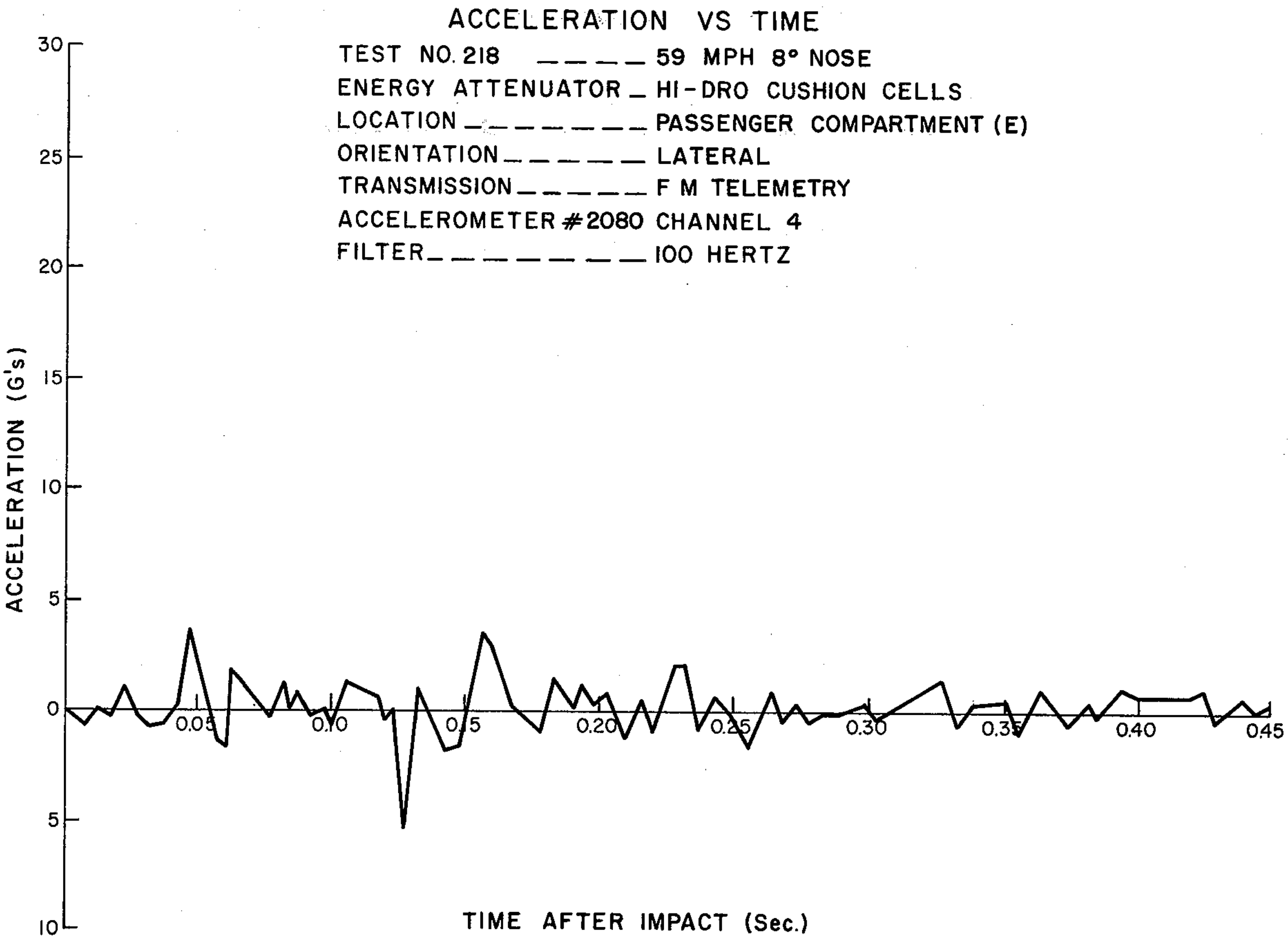
ACCELERATION VS TIME

TEST NO. 218 ——————— 59 MPH 8° NOSE
ENERGY ATTENUATOR — HI-DRO CUSHION CELLS
LOCATION ——————— PASSENGER COMPARTMENT (E)
ORIENTATION ——————— LONGITUDINAL
TRANSMISSION ——————— F M TELEMETRY
ACCELEROMETER #2085 CHANNEL 3
FILTER ——————— 100 HERTZ




ACCELERATION VS TIME
TEST NO. 218 _____ 59 MPH 8° NOSE
ENERGY ATTENUATOR _ HI-DRO CUSHION CELLS
LOCATION ________ PASSENGER COMPARTMENT (A)
ORIENTATION ______ LONGITUDINAL
TRANSMISSION ______ F M TELEMETRY
ACCELEROMETER #2084 CHANNEL 1
FILTER ________ 100 HERTZ
10.1 G's Avg.
ACCELERATION (G's)
30
25
20
15
10
5
0
5
10
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
TIME AFTER IMPACT (Sec.)


ACCELERATION VS TIME
TEST NO. 218 ——— 59 MPH 8° NOSE
ENERGY ATTENUATOR — HI-DRO CUSHION CELLS
LOCATION ——— PASSENGER COMPARTMENT (E)
ORIENTATION ——— LATERAL
TRANSMISSION ——— HARDWIRE
ACCELEROMETER #589 CHANNEL G
FILTER ——— 100 HERTZ
ACCELERATION (G's)
30
25
20
15
10
5
0
5
10
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
TIME AFTER IMPACT (Sec.)


ACCELERATION VS TIME
TEST NO. 218 ———— 59 MPH 8° NOSE
ENERGY ATTENUATOR – HI-DRO CUSHION CELLS
LOCATION ———————— PASSENGER COMPARTMENT (E)
ORIENTATION —————— LATERAL
TRANSMISSION —————— F M TELEMETRY
ACCELEROMETER #2080 CHANNEL 4
FILTER ———————— 100 HERTZ
30
25
20
15
10
5
0
5
10
ACCELERATION (G's)
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
TIME AFTER IMPACT (Sec.)

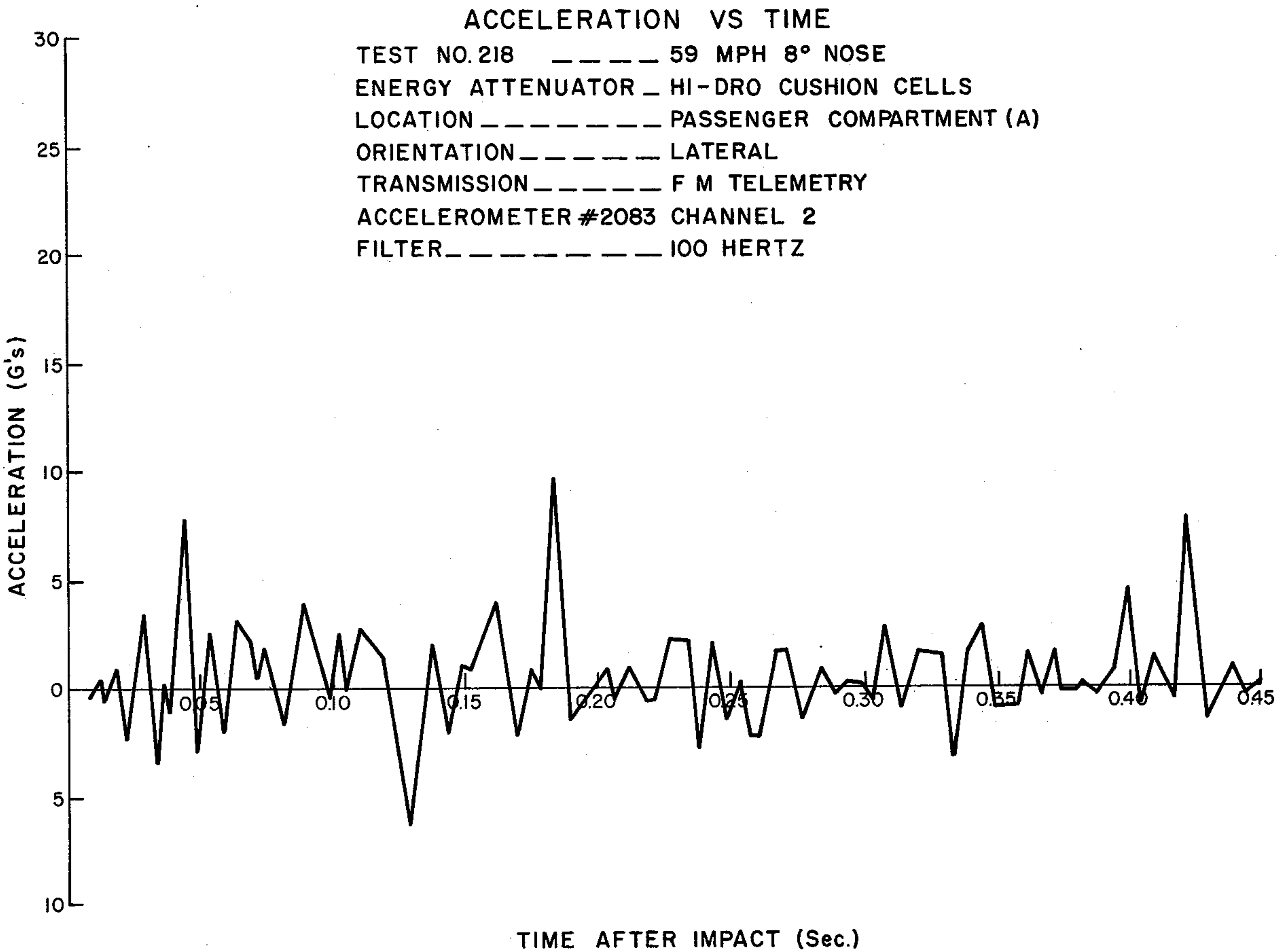
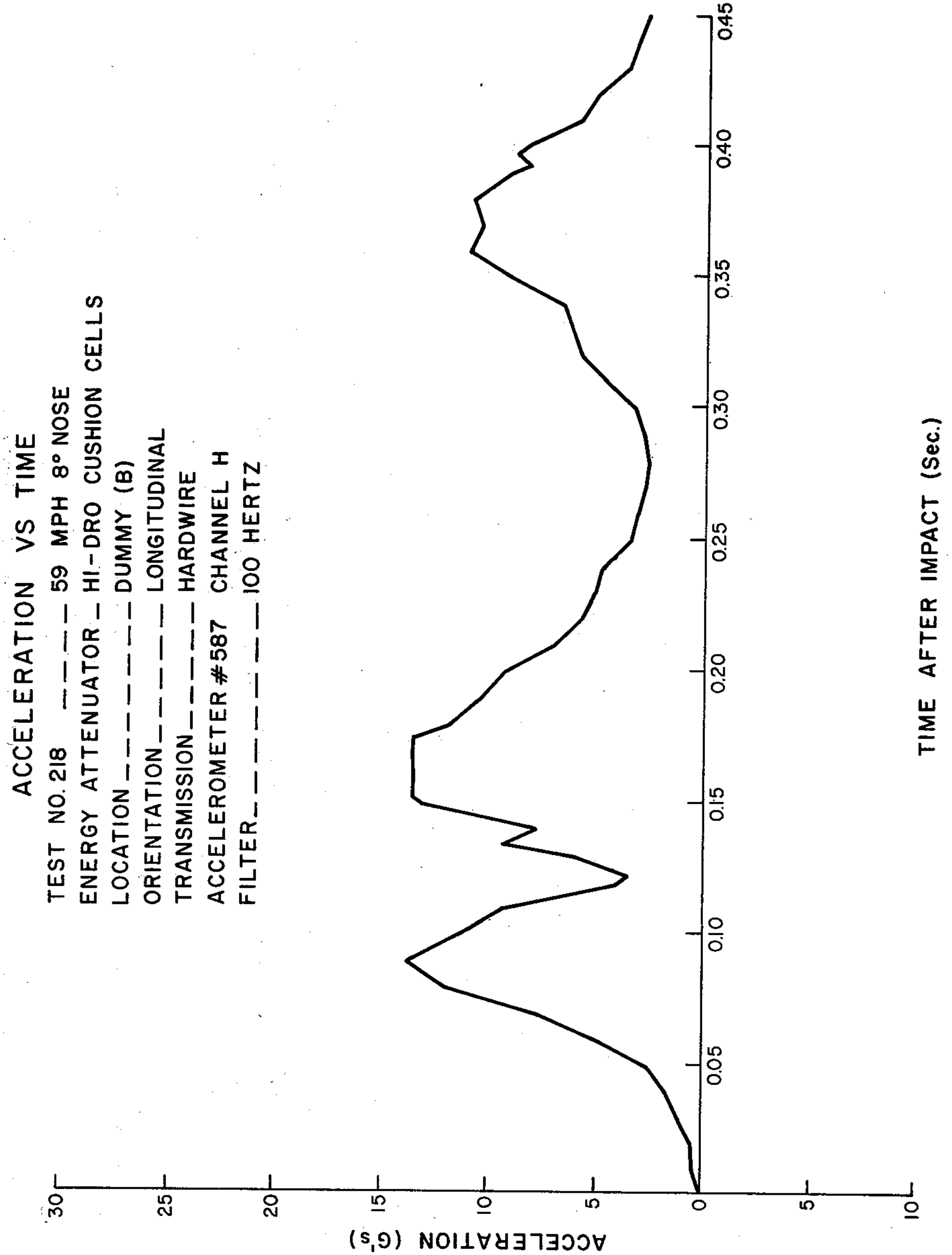
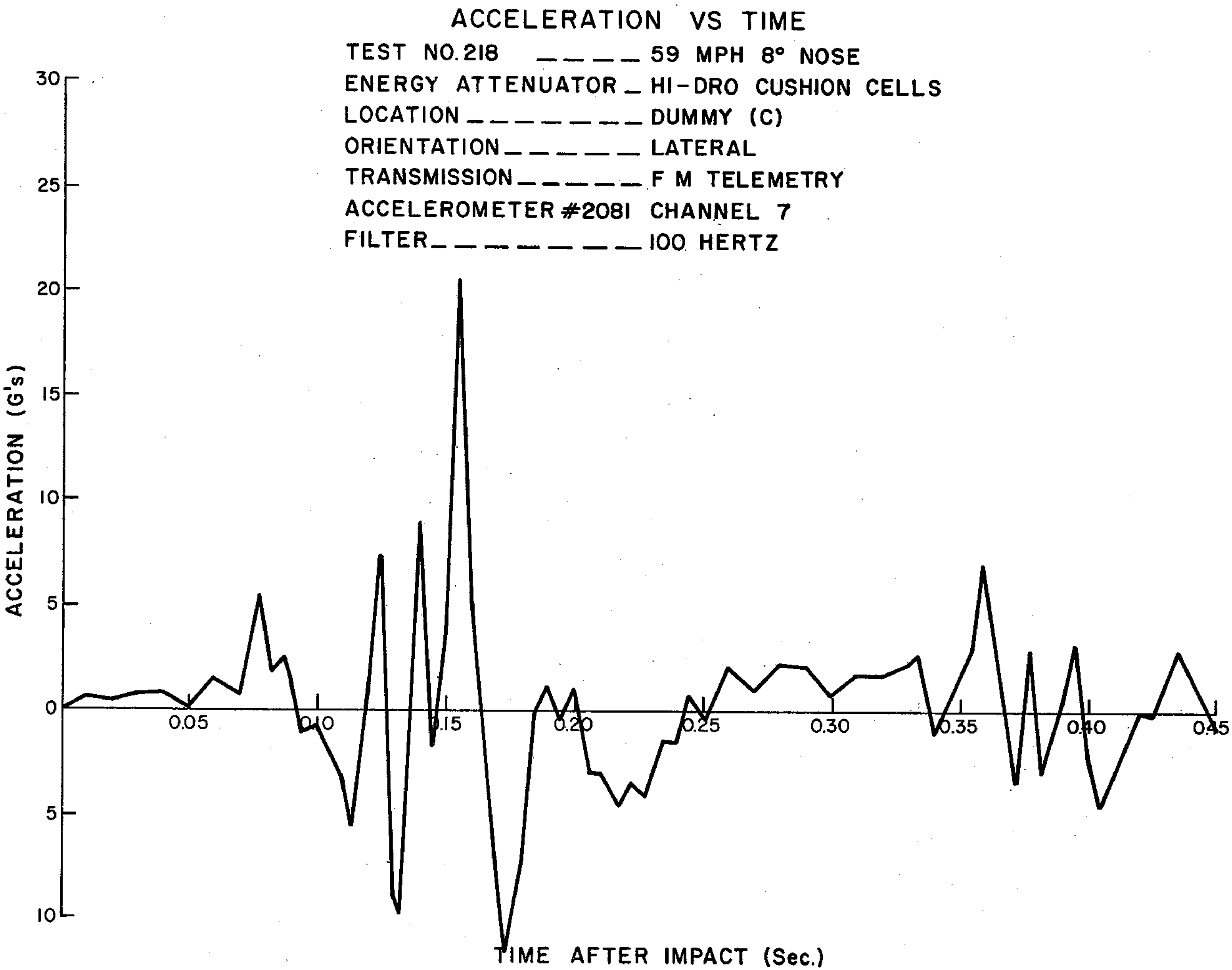

ACCELERATION VS TIME
TEST NO. 218 ____ 59 MPH 8° NOSE
ENERGY ATTENUATOR _ HI-DRO CUSHION CELLS
LOCATION ________ PASSENGER COMPARTMENT (A)
ORIENTATION ______ LATERAL
TRANSMISSION ______ F M TELEMETRY
ACCELEROMETER #2083 CHANNEL 2
FILTER _________ 100 HERTZ
ACCELERATION (G's)
30
25
20
15
10
5
0
5
10
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
TIME AFTER IMPACT (Sec.)

PLATE A-24


ACCELERATION VS TIME
TEST NO. 218 — — — 59 MPH 8° NOSE
ENERGY ATTENUATOR _ HI-DRO CUSHION CELLS
LOCATION_ _ _ _ _ _ _ DUMMY (B)
ORIENTATION_ _ _ _ _ LONGITUDINAL
TRANSMISSION_ _ _ _ HARDWIRE
ACCELEROMETER #587 CHANNEL H
FILTER_ _ _ _ _ _ _ _ 100 HERTZ
ACCELERATION (G's)
30
25
20
15
10
5
0
5
10
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
TIME AFTER IMPACT (Sec.)


ACCELERATION VS TIME
TEST NO. 218 ____ 59 MPH 8° NOSE
ENERGY ATTENUATOR _ HI-DRO CUSHION CELLS
LOCATION ________ DUMMY (C)
ORIENTATION ______ LATERAL
TRANSMISSION _____ F M TELEMETRY
ACCELEROMETER #2081 CHANNEL 7
FILTER ________ 100 HERTZ
ACCELERATION (G's)
30
25
20
15
10
5
0
5
10
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
TIME AFTER IMPACT (Sec.)